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Classification of Pinyon-Juniper Woodlands in the Great Basin

FINAL REPORT

Classification of Pinyon-Juniper Woodlands in the Great Basin

By

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GREAT BASIN PINYON-JUNIPER WOODLANDS: THE RELATIONSHIP OF STAND PRODUCTION AND BIOMASS TO ABIOTIC PARAMETERS AND THE POSSIBILITY OF LANDSCAPE STRATIFICATION BY PINYON-JUNIPER GROWTH POTENTIALS

INTRODUCTION

The Great Basin, with its high, varied topography of regularly alternating fault block mountains and sunken sediment-filled valleys, presents a challenging array of plant communities. Ecologically, the best understood of these communities are those which have been most productive in terms of natural resources, the shrub-dominated range communities. One of the most neglected formations in terms of its ecology and recent resource utilization has been the broad belt of pinyon-juniper woodland (Pinus monophylla and Juniperus osteosperma) that occurs on a high percentage of northern Great Basin mountain ranges and associated landforms. During the nineteenth century mining boom, these woodlands and the higher subalpine forests were heavily utilized--clearcut over extensive acreage for charcoal production. When the mining industry collapsed, this woodland lay undisturbed except for minor amounts of firewood and fencepost cutting and pinyon nut harvesting. Although the present value of the potential products and uses of this formation is comparatively low, future demands and environmental concerns will require a more intensive level of management.

One key to the management of any natural resource is an understanding of the basic ecological relationships governing its distribution and production. Land managements in the northwestern United States have found that a convenient-to-use, ecologically-sound means

of inventorying and even mapping their lands is by identifying the potential for a given piece of the landscape to support a defined plant association or habitat type (Daubenmire 1952; Pfister, et al. 1977). These habitat types have been organized in a hierarchical classification, regionalized where the floristic and ecologic discontinuities demand, and dichotomous keys have been written for their identification. Initial attempts to develop a classification scheme for the pinyon-juniper woodlands of the Great Basin were headed by Utah State University and the University of Nevada, Reno from plot data gathered across a wide range of sites in the northern Great Basin. A manuscript by Tueller, et al. (1976) broadly classified the woodland into floristic regions which corresponded with the climatic regions delineated by Houghton (1969). This classification permitted only regional scale recognition and management at a very coarse level. Succeeding papers from the Utah State group have established the general trends of pinyon-juniper stand composition, particularly with regard to tree species (West, et al. 1978) and Artemisia taxa (West, et al. 1978b) as correlated with region, topography and successional status.

After the 1975 field season, it became obvious that a traditional vegetation-oriented classification of the type achieved for the Montana-Idaho area (Pfister, et al. 1977; Steele, et al. 1979) would be extremely difficult to achieve. Some of the major reasons for vegetation classification of this formation type being difficult to achieve at this time follow:

1. Floristically, the region is poorly understood and what has been learned points to a confused positioning of mountain ranges according

to their flora (West, et al. 1978). Our preliminary data, for instance, indicated the absence of Agropyron spicatum from western Nevada mountain ranges. This species was found in the rest of the regions and was indicative of better sites. A. spicatum has been recognized as an indicator species and has been used to name many plant associations in Nevada and surrounding states (Zamora and Tueller 1969). Accepting the floristic divisions of the Great Basin would have necessitated complete sampling over each one, a truly prohibitive task in the time alloted.

2. The woodland successional processes that have been described qualitatively indicate that one can expect the overstory to have such a marked effect on the undergrowth that at some stages, virtually no undergrowth exists (save for annuals) until sufficient overstory mortality occurs to open up the stand (Springfield 1976). The vegetation classification cannot proceed in the absence of undergrowth species to serve as environmental indicators.

3. Further, even if a species maintains its presence, its quantity changes so remarkably with time and overstory coverage that keys to vegetation based on cover estimation would be completely negated by successional process.

4. The previously remarked-on,wide-scale woodland disturbance of the late 1800s, coupled with the hypothesized frequency of wildfires prior to the advent of white settlements, has caused some late seral and climax habitat types to be very rare, if they exist at all, at the lower end of the woodland. Such stages are valuable for documenting the course of succession and identifying the true vegetational potential of the landscape.

In 1976 we determined that rather than overlapping the efforts of the Utah State group in regard to vegetation classification as it relates to potential, we would develop ancillary measures of site potential. Our principal objective in this study was to develop a classification scheme for the Great Basin woodlands based on site potential. We have attempted to develop a model for estimating aboveground primary productivity of woodland stands on the basis of site factors, stocking, structure, and species composition. The pinyon-juniper woodland presents a unique physiognomy and an opportunity for assessing productivity and biomass across a broad spectrum of habitats. While tree site index, as an estimator of site potential, is a routine approach with conventional forest species, one year's observation of woodland species indicated that stocking densities markedly affected tree morphology (height: crown width) and that stocking densities were not related in a consistent manner to abiotic parameters and might only reflect the woodland cone crop for the year previous to disturbance. These observations seemed to discount a site tree approach to classification despite the successful regression molels of site index-abiotic parameters of Daniel, et al. (1966).

Pinyon and juniper are dominant or codominant over a vast extent of the woodland and are joined only at higher elevations by minor amounts of Cerocarpus ledifolius (except for localized areas on the west slope of the Sierras where woodlands intergrade into forests of the Pinus ponderosa Province). The undergrowth of midseral to late seral and climax woodland communities is very depauperate in species richness and biomass; the average canopy coverage is less than 3 percent. The great

majority of both biomass and production in these stands is invested in the tree component. The above facts, coupled with the availability of allometric relationships developed by Miller, et al. (1979) for P. monophylla and J. osteosperma, presented the unique opportunity for obtaining total aboveground biomass and production estimates of complete stands dominated by either of the two species. This approach is unique in that ground truth inventories of stand aboveground production have never been attempted on such a regional scale --neither has measured primary productivity been related to abiotic parameters at this scale.

METHODS

Sample Stand Selection

The area of concentration, the northern Great Basin, was divided roughly following Cronquist, et al. (1972) into six regions (west, central, northeast, southeast, east, and south(Figure 1), hypothesized to have distinctive combinations of floristic compositions, climatic regime, and ecologically influential geological features. Time restrictions permitted sampling of only the first four listed regions.

For each region, an attempt was made to sample as wide a range as practical of combinations of slope angle, aspect, elevation, and slope position. Initially, a rigid design had specified discrete combinations of the above variables, but these specifications, coupled to additional criteria regarding vegetation composition, resulted in prohibitive search times. Generally, if a relatively undisturbed mature

portion of the woodland were located, stands of as many contrasting ecologies as possible were subjectively selected on the basis of the following criteria: reasonable uniformity in site potential (as assessed by examination of microtopography) and stocking structure, relative homogeniety of the vegetation, and freedom from recent disturbance (grazing excepted). Early seral stage sites with an appreciable undergrowth were avoided; sites with low tree densities (low stocking rates) were accepted if their undergrowths were minimal (less than approximately 10 percent total canopy coverage) and the trees were predominantly mature. A concerted effort was made to avoid disease-infested areas, but dwarf mistletoe (Arceuthobium spp.) is virtually ubiquitous. Canopy gaps, where a large tree or tree groups had died and ostensibly removed a considerable portion of the stand area from production, were avoided. With the above stand selection method, areas of interest to managers (e.g., invasion and reinvasion sites and young alluvial fan sites) were largely excluded because a high proportion of the growth and biomass is invested in the shrubs and forbs, which are not incorporated in the model at this time.

Extreme sites, such as narrow ravine slopes and ridges, were avoided. Soils judged to be atypical for a region were to be avoided, but stipulations in this regard are more easily stated than observed.

Site Measurements

The growth and biomass of pinyon-juniper stands are determined by complex interrelationships of climate, topography, edaphic conditions, geological features and stand structure. Because intensive climatic

data are lacking for these remote areas, stand topographical data (i.e., elevation, aspect, slope angle, position on slope, and geographical position [range, township, section]) were substituted.

Abbreviated soil profile descriptions were made according to the Soil Survey Manual (1951) for each stand in a soil pit subjectively located in a position thought to represent a modal condition for the stand, usually on the periphery of a mature tree canopy. Pits were dug to one meter in depth, bedrock, or an indurated caliche layer, whichever came first. Samples of each designated horizon were returned to the laboratory for a determination of the coarse fraction (material > 2 mm in diameter), a quantity that was also field-estimated.

From the > 2 mm fraction for each horizon, the textural composition was determined by the Bouyoucos hydrometer method (Moodie and Koehler 1973) and a 15-bar water-holding percentage was determined on two to three replicates (Richards 1949). An index of the water-holding capacity for a profile was computed by multiplying the horizon depth by the percent of soil in the horizon, and by the 15-bar water-holding value, and summing over all horizons. One-third-bar matrix potential (approximate field capacity), though it would have permitted computation of the available water-holding capacity, was not taken because of the tendency for this measure to seriously overestimate water retention on sieved samples (Elrick and Tanner 1955).

Stand Measurements

The sampling method devised for this study is a variation of line sampling in which sampling probability is proportional to crown diameter.

Based on data from New Mexico and Arizona (Howell 1940), indicating that pinyon growth rates are approximately proportional to stump diameter squared, sampling stand growth rates should be most efficient if trees are sampled in proportion to diameter squared (Bitterlich point method). The crown morphology of pinyon and juniper, wherein the trunk may possess branches to stump height (30 cm) or below, thus obscuring the tree bole(s) in question and background trees, precludes the use of angle gauges to select sample trees. The branching pattern which prohibits efficient use of point methods is a boon to line sampling because the projection of the crown perimeter to ground level is accurately accomplished, especially in younger stands. These crown dimensions provide an additional variable of potential use in allometric biomass and growth equations.

The deployment of the sampling system can be modified to fit the shape of the stand, but usually consisted (70 percent of total number of sampled stands) of six 30-meter lines spaced six meters apart and oriented parallel to the slope contours. Five 30-meter lines were employed on only ten percent of the stands; these were high-density, north slope stands or younger even-aged stands. Approximately 20 percent of the stands were sampled with from seven to nine lines; these stands almost invariably are south slope positions of low tree density or very old, overmature stands.

Computations of the number of lines required to estimate the stand basal area within ten percent of the mean, assuming that six lines represent the true variation in the stand, were performed on a ten-stand

random sample. Analysis indicated an average of 28 lines would be necessary to estimate the mean within ten percent, 90 percent of the time. Clearly, this number of lines would be prohibitive, considering that each stand of six lines requires one to one and one-half days and would be impossible when trying to satisfy the sampling criterion of remaining on a homogeneous site. Visual inspection of stand relative homogeniety determined the number of lines to be sampled. A check of the procedures on ten stands from a range of stand structures indicates that from 60 (on young, high-density sites) to 95+ percent (on old or open sites) of the stems are actually selected. Line sampling of these stands is thus very comparable in terms of area inventoried to the more conventionally employed complete quadrat inventory (Whittaker and Marks 1975) used in production studies of similar vegetation types.

All trees whose crowns, when vertically projected, intercepted the line were sampled. The variables measured for each tree were crown diameter (C_{D_1}, in dm) perpendicular to the transect line, maximum crown diameter (C_{X_1}, in dm), crown height (dm), and stump height diameter (SHD, in cm at 30 cm from the ground). In addition, for each tree, foliage density (on a scale of 1 to 9), crown position class (dominant, codominant, intermediate, suppressed), and the numbers of forks and branches greater than 7.6 cm (3 in.) in diameter were recorded.

For radial growth analysis, increment cores, including at least ten years' growth, were taken at stump height from four quadrants of trees that were less than 35 cm in SHD and six equally spaced cores

were extracted from trees greater than 35 cm in SHD. With progressive summer drying, juniper became increasingly difficult to core and had to be cut and the sections taken for laboratory ring width analysis. The tendency toward multiple forking at or below stump height in pinyon, and especially in juniper, necessitated counting each separate fork as a sampled individual, if the fork's crown intercepted the line. The second year, four to six dominant pinyons per stand were cored for age.

The computation of A_i, the equivalent plot area for each sampled tree, is: $A_i = (n \cdot L\, C_{D_i} + (C_{X_i})) \times 10^{-4}$ ha, where n = number of lines sampled and L = line length (m). Stand parameters such as growth rate (kg/ha/yr) or biomass (kg/ha) are computed as the sum of the periodic annual increments (g_i) or biomass (b_i) divided by their equivalent plot areas (A_i); e.g., G (growth rate per stand) = $\Sigma \frac{g_i}{A_i}$ or B (biomass) = $\Sigma \frac{b_i}{A_i}$. Because height growth rate contributed much less to individual growth, it was determined indirectly from allometric equations developed by Miller, et al. (1979).

Ancillary data potentially useful in explaining stand growth and development, such as the type and extent of man-induced disturbances (e.g., grazing by domestic stock and fence post cutting) and tree injury through insect and animal damage were noted.

Allometric Estimation of Growth and Biomass

The allometric equations for growth and biomass of P. monophylla and J. osteosperma applied to the stand data gathered in this study were developed by Miller, et al. (1979) in a related companion project. P. monophylla (72 specimens) and J. osteosperma (30 specimens) that spanned a size range up to a SHD of greater than 40 cm were sampled

from all form classes from a wide spectrum of site conditions. Table 1 gives the linear regression equations and associated statistics for J. osteosperma and P. monophylla. It was felt that linear multiple regression equations would more adequately accommodate the enormous form differences encountered in these woodland species and, additionally, they would avoid the systematic bias introduced by logarithmic equations (Baskerville 1972) and obviate their correction (Beauchamp and Olson 1973). Though logarthmic equations model tree biomass or growth more realistically than linear ones because they provide for changing dimensions of tree fractions relative to one another, our multiple linear equations explain as large a percentage of the variation in the predictant as published logarthmic forms (see Whittaker and Marks 1975). The annual death and loss of tissues, such as leaves and cones, which is necessary to arrive at true net primary productivity, has not been estimated, as it would have been entirely too time consuming. These losses are minor and constitute less than five percent of total aboveground production based on results from mesic forest ecosystem studies (Crow 1978). Cercocarpus ledifolius formed a significant component of some higher altitude stands. To account for its contribution logarithmic equations developed by Whittaker and Niering (1975) for C. breviflorus, a species similar in form but more diminutive, were applied to our data.

Cores extracted for growth analysis were measured to the nearest 0.1 mm using an ocular micrometer, superimposed on the field of a variable power microscope. The ten-year period of measurement was 1966 to 1975. To ascertain that the correct increment of radial

growth was measured for each region, a brief dendroecological analysis was conducted following the prescriptions of Stokes and Smiley (1968) and Fritts (1976). Climatic data for four stations representing four geographic regions--western (Minden, NV), central (Austin, NV), southeastern (Adaven, NV), and eastern (Ely, NV) were summarized by month for the period 1956 to 1975. Monthly precipitation and temperature data were combined into variables hypothesized to be controlling tree ring widths and tested against tree ring width response.

Tree ring widths used in the regression analysis were averages computed from measurements (to the nearest .02 mm) of ten to twelve dominants or codominant pinyons per site. Though all cores were scanned for sensitivity, only the most sensitive ones were used in computations. Because no significant trend of decreasing ring width with increasing age could be established for the 20-year period, ring width standardization using exponential curve fitting (Fritts 1976) was obviated and supplanted by the conventional standardization where Z_i, the standardized ring width for any one year, is equal to $\frac{X - X_i}{s}$.

The correlation between tree ring width and precipitation for the period October to May was strong, highly significant, and facilitated the recognition and measurement of the ten-year increment of concern, especially when missing rings were suspected. Very old or suppressed trees presented such narrow and partial ring structures that a reasonable estimate of the ten-year increment replaced an accurate measurement.

$$\text{Tree ring mean sensitivity, } ms = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2\,(X_{t+1} - X_t)}{X_{t+1} + X_t} \right|,$$

where X_t denotes annual ring width and t the year, as a measure of the relative harshness of a site (Fritts, et al. 1965), was also explored as a means of stratifying sites. Seven western and southeastern, four central, and three northeastern region sites spanning the range in production and abiotic parameters were compared for their sensitivity indices for the years 1951 or 1956 to 1975. Tree selection criteria and ring width standardization were as described above.

Statistical Approach

Determining the relative influences of individual site factors on vegetation production presents a very complex problem (Medin 1960; Sharp 1975). Site factors, both biotic and abiotic, were measured as though they were discrete entities, but in reality, they interact in a highly intricate fashion. Complicating the analysis is the probable non-linearity of response of productivity to individual site factors (Czarnowski 1962). The model envisioned to predict biomass or basal area increment was: $Y = b_0 + b_1X_1 + b_2X_2 \ldots + b_nX_n + e_{ijk} \ldots$ where the b_s are coefficients to be estimated and the $e_{\ldots}$ are error variables assumed to be randomly and normally distributed with a zero mean and common variance 0^2 (Snedecor 1956). This linear model was analyzed by reverse stepwise multiple regression, deleting all terms that did not reduce the standard error of estimate by a given amount. The individual Rs (coefficients of multiple regression) as well as the partial regression coefficients (b_i) were tested for significance. The influence of the following independent (descriptive sense) variables on whole stand

biomass increment were tested; X_1 = elevation (m), X_2 = slope (%), X_3 = aspect (azimuth - 45°, and other angular shifts), X_4 = soil depth, X_5 = 15-bar water-holding capacity of fraction 2 mm, X_6 = 15-bar value x % soil by horizon x soil depth by horizon, X_7 = township, X_8 = range, X_0 = stand age. Some of the abiotic factor interactions tested for an empirical relationship to biomass increment were: $X_1 X_1 X_2$, $X_1 X_2 X_3$, X_7-X_8, $X_1 X_7 X_8$, $X_1 X_6$, etc.

RESULTS AND DISCUSSION

Tree Ring Analysis

According to Fritts, et al. (1965), the mean sensitivity of tree ring widths reflects the severity of the site from which they were obtained. Higher mean sensitivities (greater variability year to year in ring width) are associated with stressful sites, such as found at the semiarid forest border. Lower sensitivities are linked with less frequently stressed sites, such as mesic forest interior sites. We pursued the idea of utilizing mean sensitivity as an index of stress or site placement on an environmental moisture gradient, and hence indirectly of its site productivity.

Table 2 summarizes the results from a limited number of stands sampled from a variety of abiotically contrasted sites across the northern Great Basin. For the western region, the mean sensitivities of stands 57 and 58 are very similar, yet they are quite dissimilar in

their abiotic parameters, stand 58 being a stressful south slope with relatively shallow soils. Stands 15 and 64 are north and south exposures, respectively, yet stand 15 has the higher average mean sensitivity. Stands 3 through 27 (Table 2) are located east of the Sierran foothills, while 57 and 58 are located in the Sierran foothills. Note that the differences in production or basal area increment between contrasted sites in close proximity--57 vs. 58, 15 vs. 64, 64 vs. 63, 27 vs. 63--show the more mesic stand to be more productive. This result is in accord with the expectation that decreased stress (evapotranspirational demand) results in greater production. For the whole of the western region there is no apparent relationship between either productivity or abiotic parameters and mean sensitivity.

Contrasting stands 41, 42, and 43 from eastern Nevada (Table 2) show there are no statistical differences in their mean sensitivities despite considerable differences in site parameters. However, there are distinct differences in their productivities that agree with the expectation noted above, i. e. lower stress results in higher production.

The stands from the southeastern region show (Table 2) the greatest variability in site-to-site mean sensitivity. There are statistical differences ($P < .05$) in mean sensitivity between stands 75 and 38, and stands 36, 37, 31 and 29. Stands 36 and 35 of moderate differences in aspect show no differences in mean sensitivity, but the more mesic stand has much greater productivity (0.77 vs. 1.31 kg/ha/yr). Stand 29, having a relatively low mean sensitivity of .50, is a very low production site due to its southeast exposure on shallow, stoney soil.

Stands 38 and 75 had the lowest mean sensitivities and highest

productivities of the southeastern sites. The explanation for the low mean sensitivities and high production in the absence of any extraordinary site values listed in Table 2 lies most probably in the slope positions (or age) of these two stands. Stand 38 lies downslope from a rocky ridge with very shallow soil and may receive appreciable overland flow. Though the soil of the stand was very shallow, a number of test soil pits indicated a high density of soil-filled bedrock fissures into which overland flow could penetrate. Stand 75 lies on rhyolitic alluvium 10-30 cm from an ephemeral stream course. This site quite likely receives substantial subsurface drainage that considerably augments the total amount of water received. Both stands are relatively young, < 130 years.

Central Nevada plots (Table 2), regardless of their abiotic site parameters, evidence lower mean sensitivities than those of comparable topographic positions in the other regions. Why this should be is not at all clear. Based on mean sensitivity indices computed for October through September (a precipitation period highly correlated to ring width) for the 1966-1975 period, central region precipitation mean sensitivity (Austin, Nevada, 0.454) is not markedly different from that of any other region (Minden, Nevada, 0.424; Adaven, Nevada, 0.604; Ely, Nevada, 0.364). The more stressful south slope stand 14 does have a higher, though not significantly, mean sensitivity than stand 19, a north slope stand picked as a contrast. Stand 33 was chosen as a toeslope representative and despite its predominantly southern exposure, it has a very low sensitivity and relatively high productivity. The high productivity of stand 33, compared to its upslope counterpart stand 14, or other south slope positions in the central

region data set raises the possibility of subsurface drainage playing a crucial role in determining the productivity of certain topographical positions.

For upslope positions on soils developed in place, there seems to be little correlation between stressfulness of site or productivity and mean sensitivity. Mean sensitivity may, however, have promise for identifying those sites where subsurface drainage or other means of augmenting the water input to a site could be significant factors in stand production. It should be noted here that the sensitivies reported in this paper were from closed stands of pinyon-juniper woodland--sites not purposely selected for their high sensitivities, as has been the case in other studies (Fritts, et al. 1965; Fritts 1974). This contrast in site selection criteria makes all the more remarkable the high mean sensitivities reported herein, especially the western region values (Table 2). The value for stand 63 (.85) is higher than any value cited in the literature for pinyon pine (including P. monophylla and P. edulis) and as high as reported for any other species. The extreme value of 1.14 is also not matched by literature values. These high mean sensitivity values are not the result of some random signal, but are the direct result of climatic fluctuations, as will be shown below.

To further explore the obvious hypothesis that critical season precipitation and temperature control pinyon growth, a correlation analysis between standardized ring widths and climatic parameters was conducted on a data set limited to the three regions of greatest climatic differences. The results (Table 3) confirm that, regardless of region, the combined precipitation for fall, winter, and spring can explain a

considerable amount of the variation in ring width, from 46 to 74 percent. For the western and southeastern regions, October through May and October through September precipitation are the periods with highest correlation to ring width. For the eastern region, December through June precipitation is most highly correlated to ring width. Figure 2a-f indicates the seasonal distribution of eastern region precipitation, with a bulge in late spring-early summer, compared to that of the central and western regions. This late autumn deficit and early spring bulge may explain the eastern region's having a higher December-June precipitation to ring width correlation. The precipitation to ring width correlations reported here exceed those reported by Fritts, et al. (1965) for various coniferous species in northcentral Arizona, wherein previous autumn and winter and current precipitation could explain only 29 to 51 percent of ring width variation. Our precipitation to ring width correlations are lower than those cited from Mesa Verde National Park, Colorado (Fritts 1976), for J. osteosperma and P. edulis.

The eastern region also differs from the western and southeastern in having higher significant ($P < .05$) negative correlations between March-June temperatures and ring widths (Table 3). The decrease in correlation noted for all regions between March-June temperatures and ring width and March-August temperatures and ring width can be attributed to the inclusion of summer drought months. Because radial growth in Pinus edulis usually ceases in July, to resume again with input of late summer precipitation under bimodal precipitation regimes, it follows that under northern Great Basin regimes of winter-spring precipitation, P. monophylla would cease growth under midsummer

drought. Inclusion of July and August temperatures to which the trees are not capable of responding can only serve to decrease ring width-temperature correlations. Fritts (1976) shows for both P. monophylla and P. edulis that July and August temperatures approach zero correlation with ring width and that current spring temperatures are negatively correlated with ring width. Fritts (1976), for P. edulis at Mesa Verde, Colorado, has demonstrated much stronger negative ring width-temperature correlations, up to 64 percent explained ring width variance, than are presented in Table 3. However, he shows cool and dry weather coupled with the March-May period produced a narrow ring which is contrary to our results for March-June temperatures, but concurs with our precipitation effects for the same period.

Multiple correlations for sites not likely to be affected by subsurface drainage indicate that a high percentage (74 to 87 percent) of the variability in ring width could be accounted for by a linear combination of two or three of the variables listed in Table 3. Obviously, many more climatic variables and their interactions than listed here could be tested against ring width. A preliminary trial to test the possible effects of summer precipitation found that by adding June, July, and August precipitation in excess of one inch, correlations were improved by an additional two to seven percent (up to 92 percent explained variation in ring width).

The Ely and Minden, Nevada, stations used in the correlations are positioned in valley bottoms, in vegetation zones potentially climax in Artemisia spp., but very close elevationally (approximately 50-100 m below) to the lower margin of the juniper-dominated woodlands. Due to

cold air drainage, these stations yield average minimums that are approximately 3-3.5° C. lower than upslope positions, but their precipitation patterns and quantities are about the same as recorded upslope in the woodlands. Possibly our correlations of ring widths to climatic parameters could be improved with access to climatic data from stations more representative of the pinyon-juniper zone climate. However, the Adaven station is in the lower pinyon-juniper zone and not more than 5 km from any of the sites used in the analysis; it did not produce better climate-ring width correlations than the eastern or western region stations.

A major difference between the results of the tree ring laboratory and our study lies in the importance of autocorrelation (serial correlation). Fritts, et al. (1965) and Fritts (1974) have shown for a number of coniferous species that one year's growth can have a strong effect on the subsequent year's growth (first order autocorrelation), and even growth two and three years removed (second and third order autocorrelation). Fritts, et al. (1965) and Fritts (1974) found highly significant first order autocorrelations for their pinyon pine stands, while in our study no significant autocorrelation could be demonstrated. In fact, serial correlations were both positive and negative within a given region. No attempt was made at second or third order lags because it was reasoned there could be no reasonable biological explanation of such correlations if the first order autocorrelations were not first established.

At this time, no biologically-based models can explain why our trees do not exhibit autocorrelation. It might be speculated that

our sites are responding so strongly to climatic variations that any autocorrelation signal is overwhelmed. However, the literature contains an ample number of cases wherein climatic variation can explain as much ring width variation as it explains in our study, and yet autocorrelation is significant (Fritts 1974). Lack of autocorrelation effects in northern Great Basin populations may have an evolutionary explanation. With such a highly variable climate, putting on extra needles in fortuitous times to maximize production would leave the tree more susceptible to drought. The possibility of winter kill might increase as well when stems are still frozen and the needles are free to transpire, or when soil water is physiologically unavailable. This lack of opportunistic response may be, in effect, a conservationist response to short-term fluctuations of climate. However, there is no evidence that northern Nevada climates have greater short-term fluctuations than those of Arizona or arid California, an observation that would tend to dispel the evolutionary hypothesis.

The dendroclimatological aspect of this project has yielded some preliminary results that have important implications for pinyon-juniper stand growth. Pinyon trees respond in a strong positive manner to previous autumn, previous winter, and current spring precipitation, and negatively to spring and early summer temperature. Within a given region, the correlation of climatic parameters with ring widths is strong (except for stand 38, Table 3), which indicates that the same variable combinations exert control across a broad spectrum of site potentials.

Because precipitation is most highly correlated with ring width variability, it follows that an accounting of water input to a site

through precipitation, surface and subsurface flow, and loss through deep percolation, can best predict stand production. Site variables, primarily soil and topographic parameters, can be employed as indicators of site quality (production), but assigning values to these variables is very difficult, given the intrinsic heterogeneity of many pinyon-juniper sites. The effect of temperature as it influences evapotranspiration from a site is more easily modeled. Combining temperature and water budget values, an approximation to actual evapotranspiration should be possible; the log of actual evapotranspiration has been shown to be strongly correlated to the log of net aboveground production (Rosenzweig 1968).

Geographic Variation in Abiotic Site Parameters

In two field seasons (1976-77), a total of 106 stands were sampled from four of the six specified regions. Table 4 gives a breakdown of the specific geographic areas sampled and the predominant parent materials and numbers of stands sampled thereon. The eastern region is the most uniform in parent material, being composed primarily of sedimentary fault block ranges with the exception of the Deep Creek Range (extreme western Utah), which is composed of granites and rhyolites. The southeastern region is the most complex geologically, at least as parent materials influence soils and vegetation. Some very unusual conditions were inadvertently sampled, such as sites where rhyolite had intruded and flowed over a limestone. This produced rock that possessed a mineral suite like that of rhyolite, but that tested very positive for carbonates, even when weathered samples were taken from the soil surface.

The stands from central and western regions were developed almost exclusively on igneous substrates. The exceptions from central Nevada were higher elevation sites on siltstones and limestones. Parent

materials were not originally thought to be of major importance as variables controlling stand production and composition. This assumption will certainly have to be considered in light of the evidence presented below.

The synopsis of soil data (Table 5) indicates little difference for either averages or ranges exists among regions for soil depth, percent coarse fraction (> 2 mm in diameter), of water retention index. For all regions, slightly more than 50 percent of the profiles were skeletal (> 35 percent coarse fraction by weight), ranging from a high of 66 percent skeletal profiles for the eastern region to 43 percent for the southeastern region. The water retention index shows wide variation, approximately tenfold, within regions, the range being quite comparable among regions.

The textural class (applies only to the soil fraction > 2 mm in diameter) of over 95 percent of the profiles was sandy loam or loamy sand with the finest textured horizon being a sandy clay loam. There is a correlation between the clay content of the A, B1, and B2 horizons and the 15-bar values within regions for a given parent material. The B3 and C horizons of igneous extrusives, especially rhyolites that evidence a saprolitelike weathering response, exhibit a greater water retention potential than would be predicted from their clay or silt contents. This result may be due to the highly weathered nature of the saprolitelike material; individual grams of sand-size particles have a highly porous structure when microscopically examined. The high porosity registers as increased surface area and thus augmented water retention capacity.

For the fine fraction of these woodland soils, the 15-bar water retention capacity is high relative to literature values (Salter and Williams 1965; Nielson and Shaw 1958), averaging 14 percent and ranging up to 29 percent for soils of moderately coarse to coarse texture developed from extrusive igneous substrates. But when the relatively shallow depths and high content of coarse materials are considered, these soils quite probably pass a fraction of the water input to underlying bedrock. Given an average profile depth of 60 cm, 40 percent coarse material, a field capacity water content of 20 percent, and a bulk density of 1.5, the profile would be saturated by 10.1 cm of water, or approximately one-third of the annual average northern woodlands precipitation. It is highly probable, in nondrought years, for a considerable portion of the woodlands upslope from pediments, that water influx to soils could exceed storage capacity and thus pass on to subsurface flow.

The pH values for a given parent material type are quite similar among regions and within a given profile; no consistent trends with depth were noted. As expected, the calcareous substrates exhibited significantly higher pH values than the non-calcareous substrates. Three profiles developed from igneous materials that had intruded through a calcareous mantle displayed intermediate values. In a forest vegetation gradient from subalpine to lower timberline Pinus flexilis and P. ponderosa stands, there is a progressive increase in pH (Pfister, et al. 1977); the high pH values and diminutive physiognomy of woodland stands would place them as the natural terminus of such pH and physiognomic gradients.

Composition and Age Structure

Table 6 gives the basal area and density composition of the sampled stands by region and elevation for the three tree species. One notable trend is the increase in the importance of juniper as one moves from the western region to the eastern region. A comparable trend, though not as strong, was noted by West, et al. (1978). The general decrease in juniper importance with an increase in altitude noted by West, et al. (1978) is demonstrated in our data only for the eastern region. The lack of agreement between the trends elucidated by West, et al. (1978) and our data stems largely from the fact that our stands were subjectively chosen and a small sample size was obtained for any given altitudinal range. Our stands were selected to represent climax or late seral stages wherein the undergrowth biomass and production would be insignificant, whereas West, et al. (1978) selected their stands in an objective manner up- or downslope from a baseline elevation of 2000 m. They were attempting to characterize the current woodland composition. In our study, 2000 m generally constituted the lower limits of sampling because the relative undergrowth coverage was generally higher here than deemed acceptable for our objectives.

A considerable portion (approximately 80 of 226 stands on the basis of a successional index, or 104 of 226 stands were 125 years and younger by a cover-weighted average age) of the stands inventoried by West, et al. (1978) were early to midseral stages wherein juniper has a greater relative importance. Our stand age composition reflects a much more advanced successional status which further explains the lack of agreement in stand structure between the two studies.

Our western region stand structure, compared to those of St. Andre, et al. (1965) for woodlands of the White Mountains of California, again indicates, based on cover, density, and tree ages derived from regressions on dbh, that at all elevations we sampled much more mature communities with higher stocking rates. In fact, our lowest canopy coverages (35 percent) were comparable to their highest. Their highest tree density (596 stems/ha) was only one-third that of our highest for the western region and for the most part, our stem densities were two to six times as great (Table 6). Both studies show juniper to be relatively unimportant and sporadic in its occurrence in the western region.

Productivity and Biomass

Production, biomass, and associated stand parameters for 106 sampled stands are presented by aspect in Table 7 and by region in Table 8 for slopes greater than 15 percent. Table 9 contains results for slopes of less than 15 percent arranged by increasing elevation; these stands usually constitute upper bajadas, shallow pediment slopes, or surfaces of alluvial deposition. No statistically significant differences 5 % level) could be established for intergroup comparisons for any biomass or production measurement in either Tables 7 or 8 although several trends can be noted. Density and crown cover, basal area, basal area increment (BAI), biomass and biomass increment (BMI) all tend to decrease toward drier aspects. Regional responses (Table 8) indicate that eastern Nevada ranges (including the Deep Creek of Utah) have the lowest productivity, biomass, tree heights, and the highest stem densities. Western Nevada stands tend to have the highest regional productivities

(31 percent and 30 percent higher than eastern Nevada ranges for BAI and productivity, respectively), basal areas, biomasses, crown coverages, and tree heights. The eastern region's lower productivity may be related to regional differences in climate and substrates. Substrate influence is discussed below in a comparison of woodland types of Arizona to those of the northern Great Basin (nGB).

One salient feature of production measured by either BAI or BMI increment is that comparatively little variation exists in the aggregate comparison between contrasting sites. In justification of this comparison, note in the aspect summary (Table 7) that the average elevations, slopes, and the range in these values are quite similar between different aspects. One might expect in a climate where growth is strongly linked to effective precipitation (corroborated by the results of dendroecological studies) and evapotranspiration that greater differences in growth would be registered than the 16 percent and 17 percent differences for production and BAI, respectively, between north and south slopes. South exposures at 40° N. latitude with 33 percent inclination would have a 30 percent greater potential solar beam irradiation than north slopes of comparable inclination (Frank and Lee 1964). This increased irradiance results in south slopes presenting a more xeric physiognomy with lower tree densities and coverages (Table 7). Undergrowth production (coverage) of south slopes is also reduced relative to other aspects whereas north slope undergrowth production is higher.

Stands of shallow slopes (Table 9) were broken out as a unit because they are amenable to management and, possibly, have distinctive production relationships. Stands of these positions have the lowest average biomass, but a generally high basal area, BAI, and production values

relative to those of steeper slopes. These findings are understandable on a number of counts. Stands of these positions are generally younger than upslope positions, reflecting their accessibility to cutting and wildfire. Younger stands are, for whatever reasons, more productive than older ones (see below). Trees of these sites possess wide growth rings and greater than average foliage density. These younger trees may have a tendency to differential growth, putting more production into main stem xylem rather than height increment or lateral crown spread. This growth pattern may account for the difference between the ratio of BMI to BAI for the lower slope stands (4.79:1) and stands of steeper slopes (5.40:1, 5.00:1, 5.80:1, 5.20:1, 5.42:1, and 5.42:1 progressing from northern to southern aspects).

Lower slope positions may be intrinsically more productive due to favorable subsurface drainage patterns. Sampling paired stands for the express purpose of contrasting their slope or drainage positions resulted in the downslope position or position proximal to an ephemeral stream channel (hypothetically receiving more subsurface drainage) being more productive (Table 10). Confounding this interpretation are the older stand ages of all upslope, better drained positions; there is the possibility of stand decadence decreasing upslope productivity. The lower slopes usually have deeper soils with greater water retention capacity. It is notable that, in comparing upslope and downslope or toeslope positions on limestone parent materials, none of the positional comparisons indicated the downslope positions were more productive. This is in accord with the known pattern of fracturing of limestone bedrock allowing deep penetration of groundwater beyond the reach of root systems (Maxey 1964).

Site Indices, Tree, and Stand Ages Related to Biomass and Growth Measures

The major reason for obtaining tree ages the second sampling season was to ascertain whether a modified traditional site index tree approach might prove applicable to pinyon-juniper woodlands. Conceived of modifications of traditional site indexes were (1) total biomass accumulated per site tree divided by tree age, (2) current (1966-1975) biomass increment per average site tree, and (3) basal area increment per average best site tree. All site index values were averages of four to six trees per stand except No. 3, which was based on the three trees of highest production. The site tree approach had initially been discarded when visual reconnaissance (summer 1976) indicated that tree heights and crown dimensions seemed to be influenced by site aspect, topographic position, and stocking. These suspicions could not be statistically established. As can be seen by examining the last three columns of Tables 7 and 8, there are too many site, age, and region interactions to separate their relative effects with a limited data set. Average stand height is, however, positively correlated with stand tree coverage, $r = .39$ ($P \leq .01$) and negatively correlated with tree density, $r = -.33$ ($P \leq .01$). The work of Daniel et al. (1966) indicated that height/diameter site indexes for P. monophylla could be related with moderate success (R^2 of .53 to .64) to abiotic site parameters. However, because topographic range in sites inventoried was narrow, they confined their analysis to shallow slopes of invariably less than seven percent.

A preliminary stem analysis of five dominant and codominant P. monophylla stems from six contrasting sites (only four stands plotted for

clarity, Figure 3) in central Nevada indicated that selection of representative plot trees on traditional canopy height requirements would be problematical. Figure 3 shows that, for a given stand, a wide range in height growth rates of dominant pinyons is obtained but, for a given tree, height growth rate is remarkably constant and shows little indication of slowing with age. Meeuwig and Budy (1979) have documented that, with many more stem analyses of greater detail and from older trees (to 250+ years), within-stand variation in height (and radial) growth rates for ostensibly dominant stems is great and a distinctive feature of woodlands. They also found height growth rates of dominants to be constant with both age and varying levels of competition from surrounding trees. These observations may be explained by genotypic variation between trees within a stand and, perhaps, a coupling of this variation to microsite differences. The constant height and radial growth rates imply that volume or biomass increment is geometric for individual dominants, but not necessarily for whole stands. Height growth rate comparisons between stands, if attempted with the conventional two or three tree sample of forestry practices, could easily reverse the relative site indices of stands contrary to their true productivities.

Correlations between the above three site indexes and total stand BMI and BAI are positive, significant ($P \leq .01$), but low ($r = .33$ to .37). Certainly an insufficient amount of variation in stand production or BAI is explained by the variation in the site index to make these site indices useful to fieldmen in assessing site potential. The probable failure of traditional site index approaches and derivations thereof for inventorying site productivity was an incentive to explore whole stand

production in relation to site parameters.

Based on an analysis of four to six SHD pinyon cores from dominant and codominant trees from 62 stands, the stands ranged in their average age between 71 and 372 years with an average age of 213 years. This average age should obviously not be construed as the average age of extent woodland stands--the sample was heavily biased toward older stands. A considerable number of stands (24 of 62) were in the range of 150 to 225 years old. Their age and size structure indicates that these stands could have been generated from saplings and suppressed trees present on these sites at the most probable time of stand disturbance, the mid to late nineteenth century mining boom. A number of stands had curious structures with a few large, old trees (> 250 years), the rest of the stand being considerably younger based on SHD estimations. In a few cases the explanation of diameter-age structure was obvious; stumps with crosscut marks were found indicating that woodcutters had chosen to leave certain trees. Why these trees were left is an enigma. Backward extrapolation from their current size and form indicates that they were of merchantable dimensions at the probable harvesting time.

Judging by the age of the dominants/codominants and the sparse undergrowth coverage, we succeeded in sampling almost exclusively climax stands, a proportion of which may be decadent (see Figure 4). The average range in age between the oldest and youngest sampled dominant pinyon on a per stand basis was 91 years. The range in age of pinyon dominants/codominants was strongly and positively correlated to the average age of the stand ($r = .60$, $P \leq .01$). This correlation indicates that older closed stands are many aged despite their sometimes nearly

even aged appearance. The absence of a clearly manifested dominance, or a dominance not closely correlated to age within a given stand, presents a further definite obstacle in selecting site trees to reflect growth potential, especially in the older stands.

Pinyon ages are presumed to be underestimated by one to four percent based on the measured percentage of missing rings counted in the dendroecological samples for the 25-year period 1951-1975 extrapolated to the full period of record. Juniper was not cored for age because of the high frequency of fragmented cores obtained in initial trials and because there were usually enough dominant/codominant pinyons in any stand to yield a four to six tree sample. To ascertain stand age by coring only pinyon may give a distinct underestimate. Of the stands where junipers were cut and sectioned because they were too brittle to core, the majority would have been judged older based on the juniper ages. Some extremely slow growing junipers that occurred beneath pinyon dominated canopies were between 330-500 years old and only 10-15 cm SHD. Their ages were 60 to 220 years older than the oldest pinyon cored in the same stand. Growth ring analysis showed they had been suppressed or had grown at a reduced rate for their whole existence.

Some of the most unexpected of our findings were the high negative correlations between average stand age and BMI ($r = -.51$, Fig. 4, a and b) and BAI ($r = -.58$, results not shown in Figure 4). Though stand growth rates ostensibly decrease with age regardless of region, stand biomass continues to increase for 300+ years (Figure 4); the trend of increasing biomass is weak owing to its obfuscation by differential site potentials. Our age-growth correlations are disturbing because they may indicate that, with the preoccupation to obtain climax or "closed"

stands, we may have sampled a high production of overmature or decadent stands. An alternative explanation is that the younger stands which were not sampled as thoroughly were on better sites; an older stand on a more high productive lower slope would have had a much higher probability of being logged. Only for the western region were enough stand ages obtained to incorporate this variable into the production models. Western region stand age and range in age were, respectively, 184 years and 71-368 years. In this region 39 percent ($r = .626$, $P < .01$) of variation in BMI and 20 percent of BAI ($r = .450$, $P < .05$) are explained by variation in stand age. When stand age is incorporated with abiotic parameters in a multiple regression model, three b_i coefficients, stand age and two soil parameters, remain significant at the five percent level, predicting either BAI ($R^2 = 51\%$, CVR = 27.1%) or BMI ($R^2 = 74\%$, CVR = 14.6%).

Though study of the rates and patterns of succession in the pinyon-juniper woodlands has been long neglected, a site in western Utah has recently been intensively analyzed (Tausch and West 1977). They conclude the stands of a seral continuum have become self-maintaining tree communities in approximately 80 to 100 years and that the site will be fully occupied in terms of total tree photosynthetic biomass in just over 130 years. Because photosynthetic biomass is shown to be highly correlated to the increment of photosynthetic biomass and to the sap wood area, it follows that maximum tree net production may be attained at the point of maximum photosynthetic biomass provided respiration loss maintains a constant rate. West et al. (1978) indicate that tree cover and total tree photosynthetic biomass increase throughout the course of the sere as far as they have followed it (approximately

130 years). They indicate that further undocumented stages would include a concomitant decrease in tree density through competitive elimination of weaker specimens and a gradual increase in size of the remaining trees. This scenario implies that tree cover and photosynthetic biomass will stabilize and, consequently, so will production in approximately 130 years after initial tree invasion.

Meeuwig and Budy (1979) have shown by whole stand destructive sampling and stem analysis for pure pinyon stands in western Nevada that the rate of increase of basal area and biomass increment is constant over a considerable time span (100+ years) following the full tree domination of the site. Their results indicate, contrary to standard forestry observations (Assmann 1970, Spurr 1951), that some if not many sites may not reach maximum aboveground production in less than 50 years.

Major (1974) has compiled results from a number of biomass and production chronosequences for forests, plantations, and other formations. Some studies showed a constant rate of increase in aboveground biomass while others showed a logistic curve for biomass increments. In all studies the maximum annual rate was attained in 20 years or less (Madgwick 1976, Major 1974). For the wide variety of forest ecosystems cited, all decreased in growth rate at approximately 50 years or less and even decreased biomass in special cases. Forcella and Weaver (1977) have shown for a single, rather homogeneous plant association, Pinus albicaulis/ Vaccinium scoparium, that production varies more than twofold. They were not able to attribute the varying productivities to differences inherent to the site or to stand age. The majority of our stands have attained maximum production for the sere, and, of these, some may be decadent i.e. production has decreased

relative to a maximum rate.

Further complicating the analysis is the effect of stand composition on production and biomass. This effect has long been recognized in the species specific yield and site index tables of forestry, but only recently have accurate whole stand studies been conducted to show that production can vary with the community occupying a given relatively homogeneous site. For Lake States even aged forest stands of the same age, production (Crow 1978), and yield (Alban et al. 1978) have shown variable increases from 23 percent to 50 percent of the lowest rates. An even greater difference (150 percent of lowest rate) has been recorded for a seral Bromus tectorum dominated community on areas climax in the Artemisia tridentata/Agropyron spicatum association (Rickard et al. 1976). Those portions of the woodland that, for whatever reason, favor occupancy by the slower growing J. osteosperma over the relatively more rapidly growing P. monophylla will record lower production potentials. Thus one contributing factor to lower eastern region productivity may be the greater contribution of J. osteosperma to stand basal area (Table 6).

Relationship of Production and Composition to Climate-Microclimate and site

Figure 2a-f presents Walter's (1963) climatic diagrams for stations located in the four sampled regions and, as close as possible, to the pinyon-juniper zone; Figure 2g portrays a contrasting climate from a pinyon-juniper area with a bimodal precipitation regime. There is a general similarity among the four regions in both temperature and precipitation regimes for both the seasonal march in values and the seasonal or yearly means. The precipitation regime shows an increase in the

fraction occurring in summer progressing from west to east. However, summer convectional and Gulf component frontal storms in Ely or Pioche contribute only a fraction of the amount contributed by the Gulf component to Sedona, Arizona where the late summer precipitation curve exceeds the termperature curve (Figure 2g). October through May precipitation and temperature (or a comparable late autumn-winter-spring period) are critical to tree growth on semiarid lands as stated by Fritts (1975) and corroborated by our dendroecological studies. Consistent differences among regions for critical climatic periods, as well as differences among regions for given periods, i.e., 1966-1975, could be a source of differential growth among regions and a source of error in regional models of production.

The critical period climatic depiction (Table 11) shows no consistent trend by region for precipitation for the period 1966-1975 relative to the long-term record for this period. The greatest percent difference between stations for precipitation for the ten-year period versus the long-term average was 16.5 percent between Pioche and Adaven, both stations in the southeast region. This critical period precipitation difference between Adaven and Pioche is a probable source of noise in a model of regional production.

An important trend is the increase in precipitation during the critical October-May period moving east to west; precipitation for this period in Ely and Pioche is approximately 20 per cent less than that in Minden. This reduced percentage of critical period precipitation in the northeastern woodlands could possibly account for their reduced biomass and production relative to that of the more westerly regions (Table 8).

The ten-year record (1966-1975) of critical period precipitation

as a percentage of the total received over these years, compared to the long-term average for this critical period's percentage contribution to total precipitation, shows a remarkable similarity for all stations. Accepting the importance of late autumn-winter-spring precipitation to tree growth, it follows that the 1966-1975 interval is very representative for projection of long-term woodland growth rates.

The ten-year critical period precipitation difference between Adaven and Pioche is not unusual in Great Basin semiarid climates where yearly and spatial variation is extreme (Wernstedt 1960). Loope (1969) has documented, via snow survey and runoff data, spatial variation in precipitation in central and eastern Nevada ranges. At the 3050 m contour of the Ruby Mountains, precipitation decreases south from the Ruby Dome area (113 cm/year) to the area south of Harrison Pass (63 cm/year), a distance of only 30 km. Precipitation in the Toiyabe Range, 160 km southwest of Elko with elevations to 3595 m, probably does not exceed 63 cm/year (Loope 1969).

The gradients of increasing precipitation with elevation are also highly variable across the northern Great Basin. The gradient of precipitation with elevation over a span of approximately 1000 m in the Ruby Mountains is 58.5 mm/100 m in the Lamoille-Ruby Dome vicinity and decreases to 25.4 mm/100 m in the Harrison Pass vicinity; in the Toiyabe Range (Austin, Nevada vicinity) the gradient is 20.5 mm/100 m. The gradient decreases toward the west to 4.5 mm-20.0 mm/100 m in the Virginia City area of the Virginia Range (using, respectively, Carson City and Reno as the base stations). Between Lake Tahoe and vicinity, and the Truckee Meadows and Carson Valley to the east, the gradient is much steeper, 50.2 and 35.2 mm/100 m, respectively. The steeper gradient of

the Truckee Meadows compared to Carson Valley reflects the relative location of the two stations within their valleys; the Carson station receives more winter storm spillover because of its closer proximity to the Sierran front. For eastern Nevada betweeth Ruth and Ely, 8 km to the east and 175 m lower, the gradient is 44.5mm/100 m, but between Ely and Lehman Caves, 65 km to the east and 175 m higher, the gradient is 65.8 mm/100 m. The gradient in the Santa Catalina Mountains of Arizona is approximately 31.6 mm/100 m over a 1,800 m range in elevation.

Differences in local precipitation gradients are most related to the origin and course of the storm tracks as they impinge upon local orographic features. With four major components responsible for the bulk of Nevada's weather (Houghton 1969), significant intraregional and interregional variations in precipitation gradients, as documented above, can be expected to strongly influence vegetation distribution and production. Adding to this complexity is a vegetation zone climate where the bulk of precipitation is snow. Initial distribution and redistribution of snow according to prevailing winds and microtopography may plan prominent roles in plant community distribution (Billings 1969, Yoshino 1975). Over considerable extents of northern woodlands where surface roughness and slope gradients are relatively constant, as on lower pediments and upper bajadas, precipitation distribution may be expected to follow rather well-defined gradients. Upper pediments, with their sharply incised canyons, steep ridges, and convoluted mountainous topography, pose formidable challenges in the modeling of their precipitation distribution.

Research on snow accumulation and ablation in small round forest clearings, varying in width from one-fourth to six times the tree

height (H) of surrounding homogeneous forest cover, indicates that the snow water equivalents in each opening size exceed that of the surrounding forest (Golding and Swanson 1978). The excess is greater with increasing opening size--from 15 percent greater for one-fourth H to 73 percent greater for six H. In pinyon-juniper stands, where discontinuous canopies and openings of various sizes are the rule, the possibility of highly significant redistribution of precipitation is a factor which has not been evaluated in this or other studies. Stands of discontinuous or higher crown cover, relative to those of lower or patchy cover, may lose more precipitation through crown interception and redistribution to openings and, thus, are less productive than would be predicted by their macroclimatic regime.

To ascertain how our production values compared to those generated by models based on other's production and climatic data (Leith 1975), computations were made for a hypothetical midelevation woodland site of 10° C annual average temperature (T), 300 mm annual precipitation (P), and 150 and 300 mm annual evapotranspiration (AE). Leith's (1975) models for net total production yielded estimates of 1,326, 622, 355, and 774 g/m^2/year based, respectively, on T, P, and two AE values. All of these estimates far exceed the regional production values registered in our study (Tables 7 and 9); even our maximum values, when corrected to total productivity with a high root:shoot ratio of 0.5, giving approximately 350 to 375 g/m^2/year, do barely overlap the computed values based on AE. Examination of Leith's models reveals a particularly wide scatter of values about the least squares curve; a given climatic parameter value in the range of average northern woodland values is associated with a three to four range in production. Our production data for northern

Great Basin regions (Table 8) exhibits a similar range of values.

Rosenzweig's (1968) oft cited model of net aboveground production for climatically disparate regions is based on computed actual evapotranspiration; it produces an estimate of 283 g/m^2/year when computed with 300 mm AE. This value just exceeds our maximum woodland value of 249 g/m^2/year. If we compute AE for a more ecologically significant period, the October-May soil water recharge period and growing season when photosynthesis is not severely diminished due to soil drought, Rosenzweig's formula gives a productivity value of 156 g/m^2/year (assuming AE of 210 mm). This value just exceeds the average production value (137 g/m^2/year for western region woodlands. "Walter's ratio," 2 g production/1 mm precipitation (Leith 1975), though derived from the analysis of arid region grasslands, grossly overestimates woodland aboveground production by two to fivefold.

Production measurements from the Columbia Basin of Washington along an inferred gradient of increasing moisture gave the following productin values for the specified climax steppe communities: (1) Agropyron spicatum/Artemisia tridentata, 0.82-1.15 t/ha/year; (2) A. spicatum/Festuca idahoensis, 1.47-2.53 t/ha/year; and (3) F. idahoensis/Symphoricarpos albus, 2.96-3.68 t/ha/year (Daubenmire 1975, Rickard et al. 1976). The Columbia Basin has a climate much like that of the northern Great Basin in both temperature and precipitation regimes. Daubenmire did not specify the climatic conditions of the growing season for which the production data were gathered but, for the A. spicatum/A. tridentata community of Rickard et al. (1976), growing season (October-May) precipitation averaged 200 mm over four years. According to Rickard et al. (1976) however, production of this pristine

community evidenced a notable lack of response to the typical wide (nearly threefold) variation in precipitation. Conversely, production of a Bromus tectorum dominated seral community on a site of comparable potential was 3.55 times that of the A. spicatum community and varied threefold in production over the same period. Comparable results were observed for Rhodesian semiarid savannas where perennial grasslands have been partially converted through disturbance to annual grasslands (Kelly and Walker 1976); in high precipitation years annual grass production on disturbed sites increases dramatically (400 percent) relative to moderate production increases (100 percent) on perennial grass dominated sites. Differential production responses of this nature with regard to the community composition have important implications for models of production.

Most importantly, for comparison purposes, representatives of all of the above communities (replacing S. albus with its ecological analogue S. oreophilus) were found adjacent to the woodlands usually on less rocky, finer textured soils or as seral communities on sites potentially climax in woodland. Because of the close physical proximity and inferred ecological similarity between northern desert shrub steppe communities and northern woodlands, the close agreement between the ranges of production values for the two vegetation types substantiates our production findings (Tables 7 and 8). Production measurements on pinyon-juniper and marginal ponderosa pine sites in northern Arizona converted to herbaceous cover gave a one-year result of 0.26 to 2.13 t/ha/year (Clary 1964). Because production values significantly differ year-to-year in semiarid regions, Clary's results mostly confirm the range in our values, but suggest the similarity in values between the two regions for comparable

vegetation types. The accumulation of more regional production data will obviate the use of broad-based production models which consistently and severely overestimate northern semiarid shrubland and woodland production.

If precipitation or measures of moisture stress are highly correlated to production on an extraregional scale, indirect measures of these factors should correlate well with production on a more localized or regional scale. Figure 5 shows production to vary with elevation and solar insolation (a measure of evapotranspirational stress, Frank and Lee 1966) for western region stands, but in no consistent fashion. Adding soil depth or water holding capacity to the artificial topographic-moisture gradient does not further an intuitively satisfactory explanation of why the productivity response surface is so convoluted. Response surfaces for the other regions are not presented because they are no more interpretable in the light of existing production theory. Further discussion of site-production relationships is included in the modeling section.

When stand pairs are compared (Figure 5) in the immediate vicinity of one another, chosen for their contrasting abiotic parameters, the more xeric position invariably has lower production, e.g., 15 versus 64, 57 versus 58, 2 versus 3, 65 versus 67, 66 versus 67, 65 versus 66. Such paired comparisons do not, however, lead to a model.

How can one explain the high productivities of 57 and 58, given their low elevations and relatively xeric aspects? These two stands in the Sierran foothills (Leviathan Mine vicinity) may receive carry-over precipitation from Sierran storms. This carry-over does not extend much beyond the eastern foothills and, thus, the bulk of the stands

further in the lee of the Sierras receive less precipitation and attain lower growth rates. It would be more difficult to invoke precipitation carry-over to explain the higher production values at stands 68, 120, 121, and 122 located on the east slope of the Sweetwater Range in the Sierran rain shadow relative to those of comparable topographic position in the Pine Grove and Bodie Hills (stands 65, 66, 67, 28, 30, and 32).

Our biomass and production results can be placed in a limited perspective as only Whittaker and Niering (1975) in their study of an altitudinal transect in the Santa Catalina Mountains, Arizona have analyzed natural communities of comparable physiognomy and ecology. Of their listed community types only three, Pinus ponderosa/Quercus hypoleucoides forest, Pinus chihuahuana/Quercus arizonica woodland, and pgymy conifer-oak scrub are at all structurally and functionally comparable to our woodland communities. The climatic regime for the southern Basin and Range Province of which the Santa Catalina Mountains (SCM) are typical is characterized by a strong biomodal (winter and late summer) precipitation distribution (see Figure 2g for a comparable regime). The nGB is typified by cyclonic storms from the Pacific Ocean causing from 65 percent to 90 percent of the annual precipitation to be received in autumn, winter, and spring. For comparable elevations it would appear, interpolating from Whittaker and Niering (1975), that the woodlands of the SCM receive approximately twice as much precipitation as any of the stations located proximate to or within the northern Nevada woodlands (Figure 2a-f).

Although effective precipitation for the SCM is less than twice that of the nGB, it is still greater and may partially explain the higher

productivities of the southern communities (see Table 12). The late summer precipitation bulge, coupled with temperatures favorable for photosynthesis, is a further hypothetical explanation for SCM's higher productivities. SCM productivity figures are, however, considerably lower than predicted from the models of Leith (1975) and Rosenzweig (1968), in addition to being complexly and nonlinearly related to climate (as measured by precipitation or actual evapotranspiration).

Table 12 compares some stand parameters for the SCM with nGB regional averages. It is obvious that the southern communities are, for comparable altitudes or position on an inferred moisture gradient more productive than the nGB communities. This greater productivity for the SCM is reflected, not in the stem radial increments, which are closely comparable for the two areas, but in tree height growth and undergrowth production. Note that the SCM pygmy woodland sample (overstory dominated by P. cembroides, J. deppeana, and Quercus hypoleucoides) is more productive than nGB regional averages, but 66 percent of the production is accounted for by the undergrowth. If this stand is in compositional equilibrium, its structure in terms of the undergrowth constituting a majority of the production would make it comparable to very poor nGB sites of lower pediments and upper bajadas wherein J. osteosperma is the overstory dominant. The nGB woodland sites structured comparably to those of the SCM pygmy woodlands exhibit productivities in the range of 83 to 43 g/m^2/year or less; this rate is even lower than that cited by Whittaker and Niering (1975) for Larrea divaricata desert scrub (92 g/m^2/ha)! The greater productivity of Arizona woodlands is further corroborated by Fritts et al. (1965) wherein they cite mean ring widths of .68 and .81 mm for large pinyons (51.8 and 38.1 cm SHD ave.,

respectively) on ostensibly stressful sites at the margins of the woodland distribution; such growth increments far exceed those registered on our nGB sites of comparable position.

The pygmy woodland and Cercocarpus breviflorus stands for Whittaker and Niering (1975) are physiognomically comparable to nGB J. osteosperma dominated late seral to climax stands, early seral P. monophylla stands, and the relatively uncommon open Cercocarpus ledifolius stands of higher elevations. They note a decreased productivity and moisture index (based on vegetation composition) for a Cercocarpus stand developed on a limestone substrate relative to these values for vegetation on acidic substrates of similar exposure and elevation. Workers in Montana (Goldin and Nimlos 1977) have also noted a distinct difference in forest habitat types and a reduction in basal area when comparing limestone to acidic substrates. They cited P. contorta to be conspicuously absent from limestone. Goldin and Nimlos (1977) and Whittaker and Niering (1968) speculate that the production reduction on limestones is attributable to the fissured bedrock favoring rapid drainage of precipitation beyond the effective rooting depth. This explanation could be extended to the nGB eastern region woodlands wherein production is distinctly lower than that of adjacent regions (Table 7).

In California's White Mountains Pinus longaeva is the principal tree species of cold, dry, subalpine sites. Fritts (1969) reports decreased ring widths for P. longaeva on White Mountain dolomites as contrasted to granitics or sandstone substrates. Wright and Mooney (1965) note that P. longaeva is competitively restricted to dolomites, although it occurs sporadically on sandstones and granitics dominated by dwarf shrub communities. In spite of a more favorable moisture

regime on dolomite, in consequence of its high albedo, Wright and Mooney (1965) cite dolomite mineral deficiency as being the probable reason for its occupancy by tolerant P. longaeva. Neither study detailed production figures, but the inference was that dolomites were lower in production at least for the tree component of vegetation. In the complex response of vegetation to environment it is quite probable that eastern nGB woodlands are responding to both the chemical and physical peculiarities of limestone and interactions with climate.

Shrub and grass dominated communities, particularly the Artemisia tridentata/Agropyron spicatum association found on the margins of the woodland sites in the eastern region, seem to be of comparable coverage and as productive, if not more so, as communities of this association within the other three regions. This observation of comparable stature and coverage for shrub steppe community types on both limestone and acidic soils is in accord with the generalized response noted by Whittaker and Niering (1967) for desert grassland, or tundra communities, i.e. a shift to a more xeric physiognomy and floristic composition may be noted on limestone. Other studies of conventional parent material (as opposed, say, to serpentines or ash layers) indicate substrate may significantly affect production (Medin 1969, Carmean 1975).

The P. chihuahuana/Q. arizonica woodland stand (Table 12), with its relative lack of undergrowth and low stature, physiognomically corresponds most closely to the great bulk of our sampled stands, but it has a productivity roughly three to four times that of the average nGB stand and 1.8 times that of the most productive nGB stand. Furthur magnifying this difference is the fact our productivities are not corrected for losses to shedding or consumption.

The patterns of vegetation zone distribution with elevation for the nGB ranges and SCM are also different. The zone of P. ponderosa dominance drops much lower in Arizona. This runs counter to the usual upslope displacement of vegetation zones with decreasing latitude (Daubenmire 1943). Only where precipitation blowover occurs on the eastern Sierra foothills do we find P. monophylla dominated stands intermingling with those dominated by P. ponderosa. The elevations where this comingling occurs in the Sierras is still several hundred meters above where this phenomena occurs in the SCM. This upward displacement in northern as well as more southerly Great Basin areas, such as the White Mountains of California (St. Andre et al. 1965, Mooney et al. 1962), occurs in that portion of the Great Basin most strongly under the influence of the Sierran rain shadow.

The biomass accumulation ratio (BAR, ratio of aboveground biomass to net aboveground production) which reflects the accumulation of persistent, usually woody tissue is unusually high in our stands (Table 11). For forest and woodland, BAR should correlate with stand ages because of increasing biomass up to some equilibrium point. Whittaker and Niering (1975) indicate (Table 12) that their SCM BAR values for woodlands and communities of comparable structure are consistent with previously published ratios; their highest reported value was 69 for an old growth (321 years old) Pseudotsuga menziesii forest. The nGB woodland's average BAR values are greater than the highest reported values for any other vegetation type. These high values, up to a maximum of 132, may actually be slightly elevated due to an underestimate of production. The high nGB BAR values express the low growth rates of older stands and the rather old stand ages of those sampled. Meeuwig and Budy (1979) reported for

whole stand, destructive sampling stem analysis and reconstruction of stand growth, no indications of a slowing in the rate of accumulation of aboveground biomass, even in stands in which the dominants were over 200 years old. This implies that, for a woodland stand to come to equilibrium in terms of biomass and BAR is a process requiring at least several centuries.

A comparable situation in regard to biomass accumulation and equilibrium point exists in other harsh environments. Forcella and Weaver (1977) have documented biomass and production for the vegetationally homogeneous Pinus albicaulis/Vaccinium scoparium association as it occurs in Montana in upper subalpine zone environments, where low temperatures are severely limiting. Community physiognomy of the harshest of these sites is not unlike that of mesic pinyon-juniper sites. Their reported lowest productivities (net aboveground .208 T/ha/year) are comparable to the highest of the nGB woodland and range upward to .752 T/ha/year. The BAR values of the older stands of this association are greater than 60. Age versus biomass plots show biomass still increasing at 500+ years. The high BAR values of subalpine and woodland environments may represent a common response to harsh environments.

Modeling Results

Based on the given data set, a Great Basin wide pinyon-juniper woodland production model appears not to be feasible unless one is willing to accept a low percentage of explained variance in woodland production. Table 13 presents the results of simple correlation and stepwise multiple regression relationships between BMI and abiotic factors. With the listed variables retained for explaining biomass increment,

the coefficient of multiple correlation (R) is significant. Testing the b_i values (H_o:b_i = 0), however, indicates that only soil depth is significant at the conventional five percent level. Including other variables does help explain some of the variance in the biomass increment, but only a reduced degree of confidence can be placed in the overall R^2 value of approximately 15 percent. Inclusion of range and range x township variables in the production model is biologically reasonable because, as shown above (Table 13), there does appear to be a west to east trend of decreasing production.

The model of BAI across the northern Great Basin is more satisfactory than the BMI model because the abiotic parameters not only explain more of the variation in the dependent variable (R^2 = 25%), but each b_i of the retained factors is significant at the five percent level or higher. Basically the same variables explain basal area increase as explain biomass increase with the interaction of soil depth and elevation showing greater importance for basal area increase prediction. This factor interaction by itself is significant (Table 13) for predicting biomass increment, but it is deleted in the multiple regression. A probable reason for better prediction of BAI is that computation of BMI depends on some indirect determinations, the allometric relationships between various tree parameters, principally height growth and overall tree growth. Height growth is indirectly obtained from yet another allometric relationship. Too, if there is any regional bias in the allometric relationships, this bias will be manifested and magnified in the BMI results.

The explanation of so little of the variation in BMI (15 percent) and BAI (25 percent), while statistically significant, does not enable

these models to serve resource managers as management tools. The strength of the relationship between abiotic factors and production measurements is weak and model employment would lead to very serious underestimation and overestimation of the true production values. Judged according to the standards of conventional forestry, in which successful soil-site studies explain 65 percent to 85 percent of the variation in site index (Carmean 1975), our model is at the low end of the spectrum.

Further improvement of the nGB model was not achieved by deleting those stands of slopes less than 15 percent that were hypothesized to be preferentially influenced by subsurface drainage. Likewise, models constructed for slopes less than 15 percent never explained more than 31 percent of the variation in production even when slope position was included. Standardizing the stand production values of each region according to the extent which regional precipitation for the critical October-May period either exceeded or trailed that of Austin, Nevada resulted in less explained variance in production.

Compartmentalizing the model by geographic region, while seriously reducing the degrees of freedom for testing purposes, tends to remove regional climatic, parent material, and soil differences to some degree. The eastern regional models (Table 14a) have the best predictive power. An R value of .807 indicates that approximately 65 percent of the variation in BMI can be accounted for by variation in five interactive site variables. This modestly successful model loses some of its validity when the low significance levels of the component variables are noted. The best BAI model (R = .753) does not have as much explained variation, but a higher proportion of the individual b_i values have a greater

probability of being significantly different from zero. The factors retained in both models are very similar. The single most important variable is soil depth; the addition of the water holding capacity does not increase model predictivity, probably because little difference in the 15 BAR values occurs by horizon of profile in the predominantly limestone soils. Of the regional models these two are the only ones wherein elevation and transforms thereof are significantly and positively related to production.

The modeling results for the western region (Table 14b) indicate that less variation is explained (R = .694 for BMI, R = .704 for BAI) by abiotic parameters, but that more confidence may be placed in the b_i values relative to the eastern region model. Elevation and soil depth and their interactions provide most of the explanation of the variation in either production measurement. The relatively high negative correlation of slope percent with production functions may reflect the association of higher production sites with toeslopes or other positions where subsurface moisture input may be substantial.

An alternative explanation, for any variable achieving significance in these models with limited numbers of observations, lies in the sampling distributions of plots. This possibility was emphasized in the eastern region where township x range was the most significant variable in an early model version. Range x township was not associated with a true production gradient but, rather, with increasing elevation and soil depth as the path of sampling was predominantly an ascent of the western slope of these eastern ranges. While there are some biological reasons that could be advanced to explain the lower productivities of these western slopes, they are confounded by an opposite trend noted for the central

Nevada region. Range x township was thus omitted as a variable in the eastern region model. Very possibly some other variables are retained in these empirical models due only to the sampling distribution of plots.

The central region BMI model (Table 14c) has only 19 percent explained variation; it is not significant at the five percent level. Only variable X_{13} approaches conventionally accepted statistical significance and seems biologically plausible in that it contains soil depth, a variable that, by itself, is significantly and positively related to production.

Though the central region BMI model is tenuous at best, the BAI model has much more explained variation (R^2 = .44) and proportionately more significant b_i values (Table 14c). The BAI model, however, is suspect because it shows elevation to be significantly and negatively correlated with basal area increment. This correlation is probably spurious and a function of the sampling distribution of the plots. There is no reason that production should increase downslope in semiarid environments unless a number of lower elevation stands receiving subsurface or overland flow input were sampled. Our current methods have no means of ascertaining the possibility or magnitude of this input. Decreased productivity with increased elevation has been shown (Madgwick 1976) for temperate forests of, rather constant composition; temperature or radiation, not moisture, may be limiting production. For an arid region Whittaker and Niering (1975) have shown production to be positively related to elevation, but an interpretation of their results is confounded by changing species composition along the elevational (moisture) gradient. As is true of the other regional

models, soil variables, particularly depth and water holding capacity, are most important in explaining differences in central region productivity.

The regional production models reach their nadir with the southeastern region (Table 14d). The BMI model explains but 18 percent of the biomass increment variation; it is not significant at the five percent level. None of the b_i values are significant at an acceptable level, neither are any of the simple correlations.

The southeastern BAI model explains approximately 30 percent of the variation in basal area increase by variation in just three parameters, two of them incorporating soil depth as a significant variable. Without the slope percent variable, a two factor model can explain only 25 percent of the variation in BAI. The difference between the low simple correlations of soil parameters with BIA and the high degree of significance of these factors when combined in a multifactor model raises suspicions that the multifactor model is nothing more than a fortuitous mathematical formulation based on a limited data set.

Of the eight regional models only one, BMI for the eastern region, explains a large enough portion of the variation in the dependent variable to be of use to land managers. Only soil depth and water holding capacity are present in every regional model as factors of woodlandwide importance. Medin's (1960) production study of Cercocarpus montanus on a square mile of woodland type vegetation containing two different parent materials identified soil depth as the major controlling variable on both substrates. Carmean's (1975) review of forest site quality studies recognizes surface soil depth and surface textures (indices of water holding capacity) as the most important variables in predicting

site index for southern pines and conifers in general.

Daniel et al. (1966) in a broad-based study of site quality, using pinyon (P. monophylla) height at ten inches dbh as the dependent variable, were able to explain 41 percent of the variation in site quality with eight linear noninteracting variables. For this model, encompassing all provinces as well as province submodels, the most important variables were profile depth and related features (depth to lime). The results of Daniel et al. (1966), though establishing stronger correlations between their dependent variable and abiotic parameters, corroborate our findings on the importance of soil depth and the associated water holding capacity in explaining stand growth. Most significantly they found that the degree of fracturing of bedrock and associated root development was positively (highly significant) related to site index in their transprovince model. This factor we did not assess, but it could, perhaps, have increased to the explained variance in our models.

Our models are purely empirical, but they take biological realities into consideration. Our use of interaction terms is a tenuous approach; we have not as yet experimented with a full range of values for every element of each interaction term to evaluate their performances. However, in the course of sampling a broad spectrum of combinations, site variables for each region were inventoried. To avoid overextending our models they should probably be employed only in physiognomic types approximating those which were sampled. Though models explaining a satisfactory portion of the measured stand growth have not been developed, good baseline estimates of nGB woodland production have been made. The complexity of production as related to abiotic factors has been demonstrated

as has the need to compartmentalize analyses by region, i.e., by climate and geology (substrate). Future woodland studies should delve into estimating subsurface water flow and the rooting depths of trees on a range of sites to ascertain if there is a means of evaluating and incorporating subsurface water regimes into site evaluations.

The original purpose of this project was to develop models of production in pinyon-juniper woodlands that could serve as management tools in assessing their biotic potential in lieu of stratification by vegetational criteria. Abiotic parameters were to be stressed in constructing the model(s) so that landscapes currently devoid of pinyon-juniper may be monitored for their potential to produce pinyon-juniper and, possibly, other vegetation. Inventory of extent pinyon-juniper stands should be conducted with a minimum ratio of man hours to acreage inventoried. None of our models or observations indicate that easily acquired purely physical measurements or quantification of stand position in the landscape produce utilizable models of production or efficient means by which production classes could be inventoried.

Inclusion of measured vegetational paramenters was briefly explored as a potential input to a model which would increase explained variance production. Table 15a makes it clear that stand age or average height over age in combination with stand cover and abiotic parameters are important predictors of stand production as measured by basal area increment. Including site trees or stand age data acquired only with extensive sampling, and a somewhat nebulous concept in older stands, in inventories of extend woodlands is a definite possibility. The explanation of approximately 67 percent of the variation in BAI is approaching respectability for models assessing site potential. It is especially

good considering that it covers a broad spectrum of northern Nevada sites.

The 50 percent explained variation in BAI for 20 western region stands (Table 15) is an ambiguous finding that would promote the age determination of stands as a variable to be used in site productivity. A bias introduced by the sampling distribution of plots is a distinct possibility. Considering that easily accessible, harvested, and potentially more productive lower elevation or bajada stands have been preferentially harvested, their ages would spuriously be inversely related to productivity. The addition of stand cover to the multiple regression equation for the western region explains an additional 16 percent of the variation in BAI giving an R^2 value of 66 percent. If the additional biotic parameters of cover and stand height are determined for stands, which can be determined from aerial photographs, the formulation of models of production satisfactory for employment by the land manager is probable.

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Figure 1. Location of sampled mountain ranges and weather stations from which climatic summaries were derived. Western region consists of the Pinenut, Sweetwater, and Bodie Mountains and the Sierran foothills (not pictured). Central region consists of the Paradise, Shoshone, Toiyabe, Toquima, and Monitor Ranges. Northern region consists of the Schell Creek, Egan, and Deep Creek Ranges. Southeastern region consists of the Wilson Creek, White Rock, Grant, and Quinn Canyon Ranges. Mountain ranges from two unsampled regions not portrayed.

Figure 2. Walter (1963) climatic diagrams for stations within or proximal to the pinyon-juniper zone of the northern Great Basin and one contrasting station from a bimodal precipitation regime. Data of the diagrams are keyed as follows (see Fig. 1 for station locations): A. Station name; B. Elevation (m); C. Mean annual temp. (C°); D. Mean annual precipitation (mm); E. Absolute maximum temp. (C°); F. Mean daily maximum of warmest month (C°); G. Mean daily minimum of the coldest month (C°); H. Absolute minimum temp. (C°); I. Years of record, first = temp., second = ppt.; J. March of monthly ppt. means; K. Hypothetical humid period; L. March of monthly temp. means; M. Hypothetical arid period; N. Months with daily minimum temp. below 0° C; O. Months with an absolute minimum temp. below 0° C (Data from Weather Service, U.S. Dept. of Commerce).

Figure 3. Stem analysis results for the highest (solid figures) and lowest (half-solid figures) height growth rates of five sampled dominant trees per plot from four central Nevada sites centered on the Shoshone Range.

Table 1. Allometric equations employed in the calculation of biomass and biomass increments for woodland tree species

Species:

Juniperus osteoperma

Biomass (whole tree,kg) + $(21.11(D) + 512.20(H) - 37.96(H)^2 - 6.44(D)(QS)-922)(D)(C)$

R^2=.97 CV=18.2%

Biomass Increment (whole tree,kg) = $(G(38287(C)+34.12(H) + 53.17(D/H-3.21(D)(QS)^{\frac{1}{2}})+1000)(C)$

R^2=.93 CV=18.3

Pinus monophylla

Biomass (whole tree,kg) = $(55.373(D) - 5.233(D)(H) +20.545(H)^2-3.0)(D)(CX)(.001)$

R^2=.98 CV=15.7

Biomass Increment (whole tree,kg)= $(2632.0 + G(6.468(D) + 32.96(H)(F)^{\frac{1}{2}})(.001)(CX)$

R^2=.96 CV=18.4

D=stump height diameter(cm), H=height(m) CX=Crown diameter maximum(m),

CY=crown diameter, minimum(m) $C=((CX)(CY))^{\frac{1}{2}}/1000$ G=basal area increment(cm^2/yr)

F=foliage class rating,[1] integer values 1-9

Cercocarpus ledifolius

$\log_{10}$(above ground dry weight,g) = 1.8794 +2.2999 ($\log_{10}$(basal diameter,10cm))

r=.991 E=1.173*

$\log_{10}$(above ground net production,g/yr) = 1.5532 + 1.5935 ($\log_{10}$(basal diameter,10cm))

r=.979 E=1.183

[1]from Whittaker and Niering (1975) for Cercocarpus breviflorus

*estimate of relative error (antilog of $s_{\bar{y}}$ of a logarithmic regression)

Figure 4. Relationship among production, biomass, and average stand age on a regional basis. Average stand age is based on SHD age from four to six cored pinyon trees per stand. A. Results from western and southeastern regions, B. Results from eastern and central regions.

Figure 5. The relationship of western region woodland production to elevation and solar irradiation index as a two dimensional representation of the topographic moisture gradient (irradiation values computed from Frank and Lee (1966)).

Table 3. Correlations (simple, multiple, and serial) for tree ring indices and climatic variables

Region (and location of reporting station)	Stand	Simple correlations between ring indices and precipitation and temperature						Multiple Correlation (R)	Ring Indices Serial Correlation (First Order)
		Oct.-May precip.	Dec.-May precip.	Dec.-June precip.	Oct.-Sept. precip.	March-June Temp. Ave.	March-Aug. Temp. Ave.		
Western									
(Minden, Nv.)	57	.86	.81	.83	.86	-.46	-.35	.88	.067
	58	.85	.77	.78	.84	-.43	-.35	.86	-.175
	15	.77	.62	.70	.75	-.52	-.46	.89	-.115
	64	.86	.69	.77	.82	-.58	-.52	.92	-
	63	.86	.66	.77	.84	-.47	-.45	.93	-
Southeastern									
(Adaven, Nv.)	38	.74	.65	.58	.63	-.28	-.22	.81	-
	36	.81	.79	.81	.80	-.44	-.35	.89	-.050
	31	.82	.78	.76	.80	-.42	-.33	.92	-.187
	35	.83	.74	.74	.82	-.46	-.36	.92	-.123
	37	.81	.68	.66	.80	-.50	-.43	.91	-
Eastern									
(Ely, Nv.)	41	.71	.75	.87	.74	-.68	-.52	.91	.105
	43	.70	.75	.87	.75	-.76	-.53	.90	.160
	42	.68	.74	.86	.78	-.66	-.38	.86	-.023

Table 2. Tree ring analysis: Abiotic and biotic site and sample tree characteristics arranged by region

Region	Stand Number	Altitude (m)	Aspect (degrees)	Slope (%)	Soil Depth (cm)	Basal Area Increment (m^2/ha/yr)	Biomass Increment (kg/ha/yr)	Average Sample Tree shd (cm)	Average Sample Tree Height (m)	Average Sample Tree Ring Width (mm)	Mean Sensitivity (Ave. of 10-12 trees)	Range of Mean Sensitivity (by Site)
Western	57	1870	250	14	88	.282	1.53	34.4	7.4	.64	.50	.38-.70
	58	1910	178	34	51	.243	1.32	40.2	7.0	.68	.54	.42-.77
	03	2130	360	36	82	.191	1.25	33.7	9.1	.51	.68	.46-1.00
	15	1920	348	51	80	.275	1.56	25.1	6.3	.61	.79	.58-1.10
	64	1950	172	38	38	.239	1.18	37.8	7.0	.69	.68	.60-.85
	63	2080	164	18	75	.266	1.53	27.3	6.9	.45	.85	.76-1.14
	27	2450	176	28	56	.211	1.13	46.5	8.1	.56	.70	.52-.93
South-east	29	2200	143	49	50	.098	0.58	41.2	7.5	.47	.50	.37-.59
	36	2080	175	50	85	.147	0.77	33.6	6.9	.78	.71	.47-.87
	31	2150	136	38	56	.269	1.61	32.8	8.2	.56	.71	.55-.92
	35	2020	74	28	75	.231	1.31	27.2	7.5	.56	.64	.49-.85
	37	2120	260	42	92	.321	1.75	31.1	8.1	.57	.72	.49-1.13
	38	2320	74	38	15	.476	2.39	22.5	6.6	.95	.39	.21-.56
	75	2100	200	9	125+	.528	2.43	23.8	6.2	1.14	.28	.17-.42
Central	14	2360	190	58	27	.118	0.64	45.5	7.5	.42	.41	.33-.66
	08	2180	324	44	42	.272	1.47	27.7	7.0	.45	.59	.40-.74
	19	2380	19	47	74	.360	1.74	22.3	6.2	.71	.34	.22-.44
	33	2260	160	35	88	.231	1.31	29.7	6.7	.80	.39	.29-.51
Eastern	41	2250	194	36	40	.186	.95	28.3	5.6	.50	.55	.39-.70
	43	2270	245	32	42	.250	1.19	29.6	6.5	.60	.68	.48-.77
	42	2275	346	59	100+	.260	1.34	22.5	7.4	.46	.66	.48-.88

Table 5. Selected soil properties by region and horizon

Regions		a	b*	c*	d†	e	f	g	h
Southeastern	$\bar{x}$	68.4	29.5	42.8	47.2	6.93	7.68	6.86	7.80
	s	28.9	12.5	17.9	28.7	0.35	0.39	0.39	0.35
	Range	15-130(+)	7-51	9-68	8-111	6.3-7.6	7.2-8.0	5.9-7.7	7.3-8.1
Eastern	$\bar{x}$	57.2	36.4	41.2	35.6	7.13	7.82	7.10	7.90
	s	29.9	6.8	17.6	29.1	.10	0.18	0.18	0.12
	Range	18-127(+)	22-48	12-78	8-132	7.0-7.2	7.4-8.1	6.9-7.3	7.8-8.1
Central	$\bar{x}$	57.1	28.8	42.7	34.2	6.86	7.33	6.74	7.47
	s	21.7	11.7	14.9	22.7	0.28	0.12	0.52	0.32
	Range	21-102	14-70	17-70	8-100	6.4-7.4	7.2-7.4	5.9-7.7	7.1-7.7
Western	$\bar{x}$	68.6	33.4	49.1	44.9	6.57	-	6.47	-
	s	31.3	10.8	12.3	39.1	0.30	-	0.28	-
	Range	50-200(+)	15-45	30-72	9-93	5.8-7.0	-	5.8-7.1	-

a = Soil depth (cm)
b = Coarse fraction (%) A horizon(s)
c = Coarse fraction (%) B horizon(s)
d = Water retention index
e = A horizon(s) pH, noncalcic parent material
f = A horizon(s) pH, calcic parent material
g = B horizon(s) pH, noncalcic parent material
h = B horizon(s) pH, calcic parent material

*Fraction of horizon > 2 mm in diameter

†15 BAR value (%) x % soil < 2 mm in diameter x horizon depth x 10^{-1}

Table 4. Distribution of stands by region, geographic enity and parent materials.

Region	Geographic Entity	Parent Material	Stand Numbers
Eastern	Schell Creek Rng	Limestone	4,42,43,54,55,56,91
		Limestone alluvium	86,103
	Egan Rng.	Limestone	34,39,41
		Limestone alluvium	85,89,90
	Deep Creek Rng	Granite	99,100,101,102
Southeastern	Quinn Canyon Rng	Rhyolite	31,76,77,78
		Rhyolitic tuff and welded ash	35,36,37,79
		Andesite	38
		Rhyolite over shale	29
		Rhyolitic alluvium	75,83
		Limestone/rhyolite contact zone	81
		Limestone alluvium	82
		Limestone	84
	Wilson Creek Rng.	Rhyolite	45,97,51,98
		Rhyolitic alluvium	50,92
		Felsite material	95
		$CaCO_3$ enriched rhyolite	96
	White Rock Rng.	Rhyolite	46,47
		Rhyolite alluvium	48,49
		Rhyolite alluvium over limestone	93
		Limestone alluvium	94
Western	Sierran Foothills	Andesite breccia	30,26
		Rhyolite-granite	58
		Rhyolitic alluvium	57
	Sweetwater Rng.	Rhyolitic colluvium	120,121,122,68
		Andesite	69
		Rhyolite	63
	Pine Nut Rng.	Rhyolitic colluvium	65,66,67
		Rhyolitic-granite alluvium	53, 52
		Granite	15,64
	Bodie Hills	Rhyolitic colluvium	65,66,67
		Basalt (leucite)	57,28
		Rhyolitic alluvium	32
Central	Paradise Rng.	Limestone-sandstone	6,7
		Granite	5
	Shoshone Rng.	Rhyolitic/andesite alluvium-colluvium	9,8,11,59,60,61, 62,14,12,19,33
		Andesite alluvium	11
		Balsalt-andesite colluvium	104,105
	Toiyabe	Granite	21,22,18
		Andesitic colluvium	10
	Toquima	Rhyolite-shale colluvium	13
		Shale-siltstone	23,16,24,20
		Extrusive igneous alluvium	17
	Monitor	Andesite	25
		Extrusive igneous alluvium	70
		Rhyolite colluvium	71,72,73,74

TABLE 7. Production and biomass by aspect

Aspect		Elevation (m)	Slope %	Basal area (m^2/ha)	Basal area increment (m^2/ha/yr)	Biomass (t/ha)	Biomass increment (t/ha/yr)	Crown cover (%)	Height (dm)	Density (stems/ha)
North										
Average	*n = 14	2219	33	34.8	.226	104.9	1.22	62	61	832
Range		1920-2380	17-59	20.4-52.7	.172-.360	48.3-309.2	.81-1.70	45-78	47-108	510-1115
Northeast+Northwest										
Average	n = 12	2175	27	30.8	.275	80.4	1.37	59	56	893
Range		2000-2340	17-50	24.4-48.2	.115-.350	52.9-115.1	.60-1.61	41-73	45-69	370-1430
East										
Average	n = 8	2280	33	33.3	.222	96.5	1.29	68	55	816
Range		2020-2380	10-50	25.1-41.3	.141-.476	80.5-127.6	.86-2.39	59-78	48-60	380-1420
West										
Average	n = 13	2273	34	36.0	.231	95.1	1.19	59	56	825
Range		2120-2540	22-47	21.9-66.7	.138-.327	59.1-134.9	.70-1.75	39-71	45-70	420-1340
Southeast+Southwest										
Average	n = 12	2254	34	30.6	.199	89.6	1.08	59	57	697
Range		2100-2420	16-49	19.1-54.6	.098-.269	54.7-161.6	.58-1.61	41-74	47-71	170-1120
South										
Average	n = 16	2213	33	27.9	.188	78.1	1.02	54	56	604
Range		1910-2450	18-58	12.5-36.2	.077-.266	49.2-112.4	.64-1.53	36-82	39-80	260-1030

*n = number of sampled stands

Table 6 . Stand basal area and density composition by geographic region and elevation.

Elevation Range (mx100)	Stand Parameters	GEOGRAPHIC REGIONS											
		Eastern			Southeastern			Central			Western		
		Pimo[1]	Juos	Cele	Pimo	Juos	Cele	Pimo	Juos	Cele	Pimo	Juos	Cele
19<	Basal Area*	-	-	-	-	-	-	-	-	-	20.5	-	-
	Density**	-	-	-	-	-	-	-	-	-	640	-	-
19-<20	Basal Area	7.8	41.0	-	6.6	20.6	-	21.8	1.5	-	26.9	0.8	-
	Density	110	1553	-	162	416	-	517	50	-	523	12	-
20-<21	Basal Area	17.2	14.1	-	16.2	7.7	-	14.8	8.1	-	27.7	1.0	-
	Density	547	700	-	528	291	-	592	507	-	524	1.7	-
21-<22	Basal Area	16.5	29.5	-	18.0	5.2	-	26.0	1.7	-	31.1	0.5	-
	Density	431	690	-	733	100	-	1013	84	-	594	66	-
22-<23	Basal Area	24.0	7.8	1.1	27.0	3.8	<0.1	29.3	5.4	0.1	39.1	-	-
	Density	615	243	26	691	120	6	647	189	4	390	-	-
23-<24	Basal Area	31.9	1.7	3.9	24.6	4.7	0.6	25.6	2.5	0.5	31.3	4.1	<.1
	Density	646	52	88	822	95	31	631	68	24	521	45	4
24-<25	Basal Area	27.0	4.2	1.5	23.1	15.3	-	-	-	-	41.4	1.1	-
	Density	817	132	66	372	151	-	-	-	-	690	10	-

[1] Pimo = Pinus monophylla, Juos = Juniperus osteosperma, Cele = Cercocarpus ledifolius

* in m^2/ha, ** in stems/ha

Table 9. Biomass and production and other stand parameters for sites with slope>15%; arranged by ascending elevations

Stand No.	Elev. (m)	Aspect (degrees)	Slope (%)	Basal Area (m^2/Ha)	Basal Area Inc. (m^2/Ha)	Biomass (T*/Ha)	Biomass Inc. (T/Ha/Yr)	Crown Cover (%)	Ave. Ht. (dm)	Density (Stems/Ha)
57	1870	230	14	29.5	.276	108.2	1.53	72	73	540
95	1940	350	15	36.1	.154	66.9	.81	39	45	830
92	1980	0	0	18.2	.125	32.9	.43	38	50	320
103	1980	70	7	50.0	.101	70.2	.50	32	30	1660
22	1990	350	13	23.3	.317	52.8	1.10	39	53	570
45	2000	45	14	32.9	.213	66.9	1.22	56	44	1430
53	2020	250	5	21.1	.282	79.4	1.50	61	71	320
96	2060	0	0	16.8	.188	46.3	.98	44	46	540
70	2080	310	7	22.9	.254	44.8	1.11	48	37	1100
90	2080	153	10	41.9	.214	74.4	1.19	56	38	1420
86	2080	48	10	20.6	.224	37.8	1.01	46	32	1080
9	2100	250	6	25.0	.210	71.8	1.19	62	42	1350
75	2100	200	9	22.4	.528	61.8	2.43	67	49	1320
93	2100	238	12	26.2	.177	50.3	.70	41	47	690
83	2100	278	13	21.7	.243	63.7	1.14	61	56	600
94	2100	233	15	22.5	.201	54.7	.92	47	54	680
52	2110	245	9	24.0	.515	80.3	2.49	79	51	840
11	2110	94	9	28.4	.333	84.6	1.56	63	51	820
5	2120	45	14	32.4	.180	73.7	.93	56	48	920
18	2130	230	12	21.3	.203	109.1	1.12	54	71	580
69	2140	275	10	37.3	.265	93.5	1.14	55	51	530
89	2150	260	6	44.7	.251	89.9	1.23	59	48	1260
32	2150	282	6	35.0	.289	97.8	1.50	56	55	790
1	2150	254	8	29.5	.276	108.2	1.53	72	73	540
85	2160	87	8	47.4	.157	63.3	.78	40	35	980
17	2160	74	12	17.4	.274	47.9	1.14	44	33	1300
97	2180	183	15	28.4	.196	105.2	1.16	61	80	260
121	2200	80	5	23.6	.571	76.2	2.07	47	64	380
49	2200	248	7	29.0	.220	95.3	1.20	59	71	730
48	2200	265	13	27.9	.494	79.2	2.22	81	52	1160
98	2230	250	15	32.7	.321	87.8	1.64	67	56	1560
122	2300	60	15	30.2	.332	96.6	1.48	56	70	510
72	2310	350	5	32.6	.194	89.7	1.15	65	56	680
105	2330	263	7	30.3	.270	82.7	1.21	64	47	850
n=34	2118	-	10	39.3	.267	75.2	1.28	56	52	857
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

* T/ha = metric tons/ha = kg/ha x .001

TABLE 8. Production and biomass by geographical region

Region		Elevation (m)	Slope %	Basal area (m^2/ha)	Basal area increment (m^2/ha/yr)	Biomass (t/ha)	Biomass increment (t/ha/yr)	Crown cover (%)	Height (dm)	Density (stems/ha)
Eastern										
Average	*(n = 21)	2229	28	29.2	.196	62.2	1.05	60	47	977
Range		1980-2420	6-59	20.7-69.6	.077-.248	37.8-115.7	.69-14.5	40-82	30-63	400-1660
Southeast	(n = 30)									
Average		2177	26	28.2	.244	77.9	1.20	57	57	817
Range		1980-2400	0-50	19.1-52.7	.098-.528	32.9-134.3	.43-2.39	39-81	44-71	170-1560
Central	(n = 32)									
Average		2230	27	29.2	.224	78.5	1.11	56	52	839
Range		1990-2380	5-58	17.4-66.7	.115-.360	38.7-183.0	.60-1.70	39-72	57-71	380-1340
Western	(n = 23)									
Average		2175	24	32.5	.286	109.8	1.50	63	64	580
Range		1870-2540	0-51	20.5-55.7	.168-.571	74.3-128.6	.83-2.49	47-82	51-108	310-940

*n = number of sampled stands

Table 11. Comparison of regional stations for critical precipitation period

Region	Station	Precipitation (cm) October-May		% difference between 1966-1975 and long-term precipitation Oct.-May	% long-term total occurring Oct.-May	% 1976-1975 total occurring Oct.-May
		1966-1975	Long-term			
Western	Minden, NV	18.6	19.4	- 4.3	90	90
Western	Virginia City, NV	-	23.2	-	76	-
Central	Austin, NV	27.2	26.4	+ 3.0	87	76
Southeast	Adaven, NV	22.3	25.4	-12.2	76	74
Southeast	Pioche, NV	25.0	23.4	+ 4.3	69	65
Northeast	Ely, NV	15.5	15.3	+ 2.6	69	65

TABLE 10. PAIRED STANDS CONTRASTED ON THE BASIS OF THEIR SLOPE OR DRAINAGE POSITION--FIRST LISTED STAND IS EITHER DOWNSLOPE FROM SECOND OR MORE PROMIMATE TO AN EPHEMERAL STREAM CHANNEL

Contrasted Stands	Average Age (yrs)	Basal Area Increment (m^2/ha/yr)	Biomass Increment (T/ha/yr)	Parent Material	Soil Water Retention Index	Elevation (m)	Aspect (degrees)	Slope (%)
33	141	2.31	1.31	Rhyolite	240	2280	165	35
14	259	1.18	0.64	Rhyolite	150	2360	190	58
48	110	4.94	2.22	Rhyolite	930	2200	265	13
49	230	2.20	1.20	Rhyolite	670	2200	248	7
75	73	5.28	2.43	Rhyolite	420	2100	200	9
77	236	1.38	0.72	Rhyolite	430	2220	263	47
52	71	5.15	2.49	Rhyolite	170	2110	245	9
63	136	2.66	1.53	Rhyolite	440	2080	164	18
17	@ 75	2.74	1.14	Rhyolite	680	2160	74	12
25	@180	1.81	9.3	Rhyolite	280	2200	280	32

Table 13. Multiple regression analysis of basal area and biomass increments of northern Great Basin pinyon-juniper woodlands based on abiotic site parameters.

Independent variable (X_i)	Factor Mean	Simple Correlation Coefficient(r)	Partial Regression Coefficient (b_i)	Standard Error (s_{b_i})	Level of Significance
(Dependent variable = biomass increment, (t/ha/yr) x 100)					
X_3 = slope %	26.0	-.141	.30710	.2546	0.3 - 0.2
X_5 = soil depth (cm)	63.2	.272	.36912	.1446	.02 - .01
X_6 = (soil depth by horizon) x (% soil by horizon) x (15 BAR value) ÷ 10					
X_8 = location; (range)	48.8	-.229	-.36851	.2246	0.2 - 0.1
X_9 = location; (range) x (township)	516.5	-.225	-.01331	.0114	0.3 - 0.2
Constant b_o = 136.425 R = .387 (Significant at 5% level)					
(Dependent variable = basal area increment (m^2/ha/yr) x 1000)					
X_3 = slope (%)	26.0	.240	-1.7400	.5965	.05 - .02
X_5 = soil depth (cm)	63.2	.223	-5.4481	2.3550	.05 - .02
X_8 = location; (range)	48.8	.297	-1.2498	.4955	.02 - .05
X_9 = location; (range) x (township	516.5	.293	.0595	.0253	.05 - .02
X_{11} = (elevation (m/100))^2 x (soil depth)$^{\frac{1}{2}}$	3754.2	.165	.1535	.0703	.05 - .02
X_{15} = (elevation (m/100))^2 x (soil depth)	30345.9	.208	.02202	.00906	.02 - .01
Constant b_o = 627.374 R = .498 (Significant at 1% level)					

Table 12. A comparison of northern Great Basin pinyon-juniper biotic stand parameters to those of communities of comparable physiognomy from the Santa Catalina Mtns., Arizona.

Plant Community Description & Location		*Pinus ponderosa -Quercus hypoleucoides* forest SCM**	*Pinus chihuahuana -Quercus arizonica* woodland SCM	Pygmy conifer-oak scrub SCM	*Cercocarpus brevi-florus* shrubland SCM	Western Nevada Region woodland averages	Eastern Nevada Region woodland averages
Site Variables							
Elevation (m)		2180	2040	2040	1810	2175	2229
Exposure		SW	SSE	W	ESE	N.A.	N.A.
Slope (degrees)		15	17	13	33	24	27
Cover, Individual Point (%)							
Conifers		74	32	6	-	-	-
Broadleaf Trees		42	54	4	-	-	-
Shrubs		-	6	52	33	-	-
Herbs		2	4	-	42	-	-
Cover, Tree Crown Projection (%)		-	-	-	-	63	60
Undergrowth (%)						<<5	<<5
Height (m)		15.2	7.5	2.7	3.7	4.7	6.4
Stem Density/ha	Trees	1280	2780	570	-	580	977
	Shrubs	-	10	160	3930	<200	<200
Basal Area (m^2/ha)	Trees	34.9	26.0	4.32	-	32.5	29.2
	Shrubs	-	.02	.58	2.68	-	-
Basal Area Increment (m^2/ha/yr)		.187	.238	.044	-	.286	.196
Mean Radial Increment (mm/yr)		.38	.38	.28	-	.58	.33
Weighted Mean Age (yr)		150	101	115	-	-	-
Average Age of Dominants (yr)		-	-	-	-	186	>200
Biomass, Above Ground (t/ha)	Trees	162.4	113.5	15.3	7.20	109.8	62.2
	Total	163.0	114.0	18.8	8.02	109.8+	62.2+
Production, Above Ground ($g/m^2/yr$)	Trees	491	435	64.9	125	150	105
	Total	496	446	186	185	150+	105+
Biomass Accumulation Ratio*		32.8	25.6	10.1	4.33	73.3	59.2

* Above ground biomass/Aboveground net production.

** SCM=Santa Catalina Mtns., Arizona, data from Whittaker and Niering (1975)

TABLE 11. Multiple regression analysis of basal area increment from aged stands distributed across the northern Great Basin

Independent variable	Factor Mean	Simple correlation coefficient(r)	Partial regression coefficient(b_i)	Standard error(s_{b_i})	Level of significance
(Dependent variable= basal area increment, $(m^2/ha/yr)\times1000$, for all 62 stands cored for age)					
X_3=slope,%	22.01	-.107	-1.7229	.5502	.01-.001
X_5=cosine (azimuth-45°)(X_8)	2.722	.058	-.3645	.1958	0.1-.05
X_7=(X_8)(Township)	18520.1	.190	7.4536×10^{-3}	3.0262×10^{-3}	.02-.01
X_8=(15 bar value)(%soil<2mm)(soil depth by horizon)	38.72	.194	-3.1768	1.4610	.05-.02
X_{11}=biomass/age for site trees	238.05	.340	-.1469	.0700	.05-.02
X_{13}=tree cover,%	58.88	.543	2.5825	.6652	<.001
X_{14}=(height(dm)/age)$^{\frac{1}{2}}$	.536	.644	419.773	71.3347	<.001
Constant (b_0)= -73.358	R= .816				
(Dependent variable= basal area increment $(m^2/ha/yr)\times1000$ for 20 western region stands cored for age)					
X_2=cosine (azimuth-15)	.0644	-.288	-83.2121	27.5738	.01-.001
X_{10}=(elevation(m/100))^2(soil depth(cm))	32617.4	.133	-4.7352	1.7962	.02-.01
X_{13}=stand height/site tree age	.407	.650	417.487	116.344	.01-.001
Constant (b_0)= 211.82	R=.710				

TABLE 14. Regional compartmentalization of multiple regression analysis of basal area and biomass increments of northern Great Basin pinyon-juniper woodlands.

Independent variable (X_i)	Factor Mean	Simple Correlation Coefficient (r)	Partial Regression Coefficient (b_i)	Standard Error (s_{b_i})	Level of Significance
A. *Eastern region*					
(Dependent variable-biomass increment, (t/ha/yr)x 100)					
X_2 = cos (azimuth - 45)	-.00473	.196	-86.1752	56.3220	0.2 - 0.1
X_7 = (elevation (m/100))^2	497.98	.497	- 3.3210	2.8228	0.3 - 0.2
X_8 = $(X_7)(X_2)$	.7995	.313	.1802	.1109	0.2 - 0.1
X_{10} = (elevation (m/100))^3	11146.0	.503	.1082	.0846	0.3 - 0.2
X_{12} = ((soil depth by horizon (cm) x (15 BAR value by horizon)/10)$^{\frac{1}{2}}$	7.49	.487	5.7820	1.6228	.01 - .001
X_4 = $(X_{12})^2$	61.23	.491	-	-	.05 - .01
X_5 0 soil depth, total (cm)	57.28	.541	-	-	.05 - .01
X_6 = (X_4) (% soil <2mm)/10	35.66	.453	-	-	.05 - .01
Constant (b_o) = 509.66 R = .807 (Significant at 5% level)					
(Dependent variable = basal area increase, (m^2/ha/yr)x 1000					
X_1 = elevation (m/100)	22.29	.344	20.7177	10.8214	0.1 - .05
X_2 = cosine (azimuth - 45)	-4.732	.00367	-257.772	119.906	.05 - .02
X_4 = (soil depth by horizon (cm)) x (15 BAR value)/10	61.23	.444	1.9459	.8762	.05 - .02
X_5 = soil depth by horizon (cm)	57.3	.457	-1.4095	1.0583	0.3 - 0.2
X_8 = $(X_2)(X_1)^2$	-6.293	.030	.5857	.2524	.05 - .02
X_{11} = $(X_4)(X_8)$	2001.42	.0027	-	-	.05 - .01
X_6 = (X_4)(% soil <2mm)/10					
Constant (b_o) = -304.351 R = .753 (Significant at 5% level)					
B. *Western region*					
(Dependent variable=biomass increment, (t/ha/yr) x 100)					
X_1 = elevation (m/100)	21.68	.294	12.852	12.412	0.4 - 0.3
X_2 = cosine (azimuth - 15)	.1423	-.321	-136.574	81.560	0.2 - 0.1
X_4 = (soil depth by horizon (cm)) c (15 BAR value)/10	77.13	-.206	-.3839	.1656	.05 - .01
X_5 = (soil depth (cm))$^{\frac{1}{2}}$	54.63	-.316	.2403	.1684	0.2 - 0.1
X_8 = $(X_2)(X_1)^2$	32326.5	.130	.008865	.004324	0.1 - .05
X_{10} = $(X_1)^2(X_5)$	24.1	-.532	-	-	.05 - .01
X_3 = slope, %					
Constant (b_o) = 398.319 R = .694 (Significant at 5% level)					
(Dependent variable = basal area increase, (m^2/ha/yr) x 1000					
Constant (b_o) = -398.319 R = .698 (Significant at 5-10% level)					
X_3 = slope, %	24.0	-.486	-3.7809	1.214	.01 - .001
X_6 = (15 BAR value) x (% soil <2 mm) x (soil depth by horizon (cm))$^{\frac{1}{2}}$/10	6.247	.137	-97.8846	33.49	.01 - .001
X_{10}= (elevation (m/100))(X_6))	2987.33	-.1228	.007004	.002955	.05 - .02
X_{14}= $(X_6)^2$/100					
Constant (b_o) = 707.831 R = .704 (Significant at 1% level)					
C. *Central region*					
(Dependent variable = biomass increment, (t/ha/yr) x 100)					
X_7 = (elevation (m/100))^2	500.41	-.192	.1540	.1080	0.2 - 0.1
X_{10} = (X_7)(cosine (azimuth - 45)$_1$x (slope (%))	1828.5	.035	-.00360	.00183	0.1 - .05
X_{13} = (soil depth)(15 BAR value)$^{\frac{1}{2}}$ x $(X_7)^{\frac{1}{2}}$ (cosine (azimuth -45) (slope %)	545.69	.329	.01219	.00564	.05 - .02
X_5 = soil depth (cm)	57.1	.356	-	-	-
Constant (b_o) = 180.722 R = .439 (Significant at 5-10% level)					
(Dependent variable = basal area increment, (m^2/ha/yr) x 1000)					
X_1 = elevation, (m/100)	22.34	-.435	-20.7171	9.8443	.05 - .02
X_4 = (soil depth, cm) x (15 BAR value)/10	63.10	.454	2.0208	.67269	.01 - .001
X_6 = (X_4)(% soil <2mm)	34.20	.268	-1.3858	.8794	0.2 - 0.1
X_{11} = $(X_4)(X_1)^2$ x (cosine(azimuth-45))	6.546×10^5	.174	-4.1818×10^{-6}	2.4911×10^{-6}	0.2 - 0.1
X_{12} = $(X_4)^{\frac{1}{2}}$	7.670	.475	-	-	.01 - .001
Constant (b_o) = 637.154 R = .661 (Significant at 1-5% level)					
D. *Southeastern region*					
(Dependent variable = biomass increment, (t/ha/yr) x 100)					
X_1 = elevation (m/100)	21.76	.118	406.015	313.632	0.3 - 0.2
X_3 = slope, %	26.00	-.129	-1.1718	.8336	0.2 - 0.1
X_7 = $(X_1)^2$	475.29	.111	-9.0335	7.2136	0.3 - 0.2
X_8 = $(X_1)^2$ (cosine(azimuth-45°))	68.83	-.214	-.03695	.03125	0.3 - 0.2
Constant (b_o) = -4364.93 R = .419 (Not significant at 5% level)					
(Dependent variable = basal area increment, (m^2/ha/yr) x 1000)					
X_3 = slope, %	26.00	.190	-1.5536	1.2321	0.3 - 0.2
X_5 = soil depth (cm)	68.46	.197	14.4459	4.7154	.01 - .001
X_{12} = ((soil depth (cm)) x (15 BAR value)/10)$^{\frac{1}{2}}$	8.069	.134	218.234	73.5016	.01 - .001
Constant (b_o) = 730.419 R = .544 (significant at 5% level)					

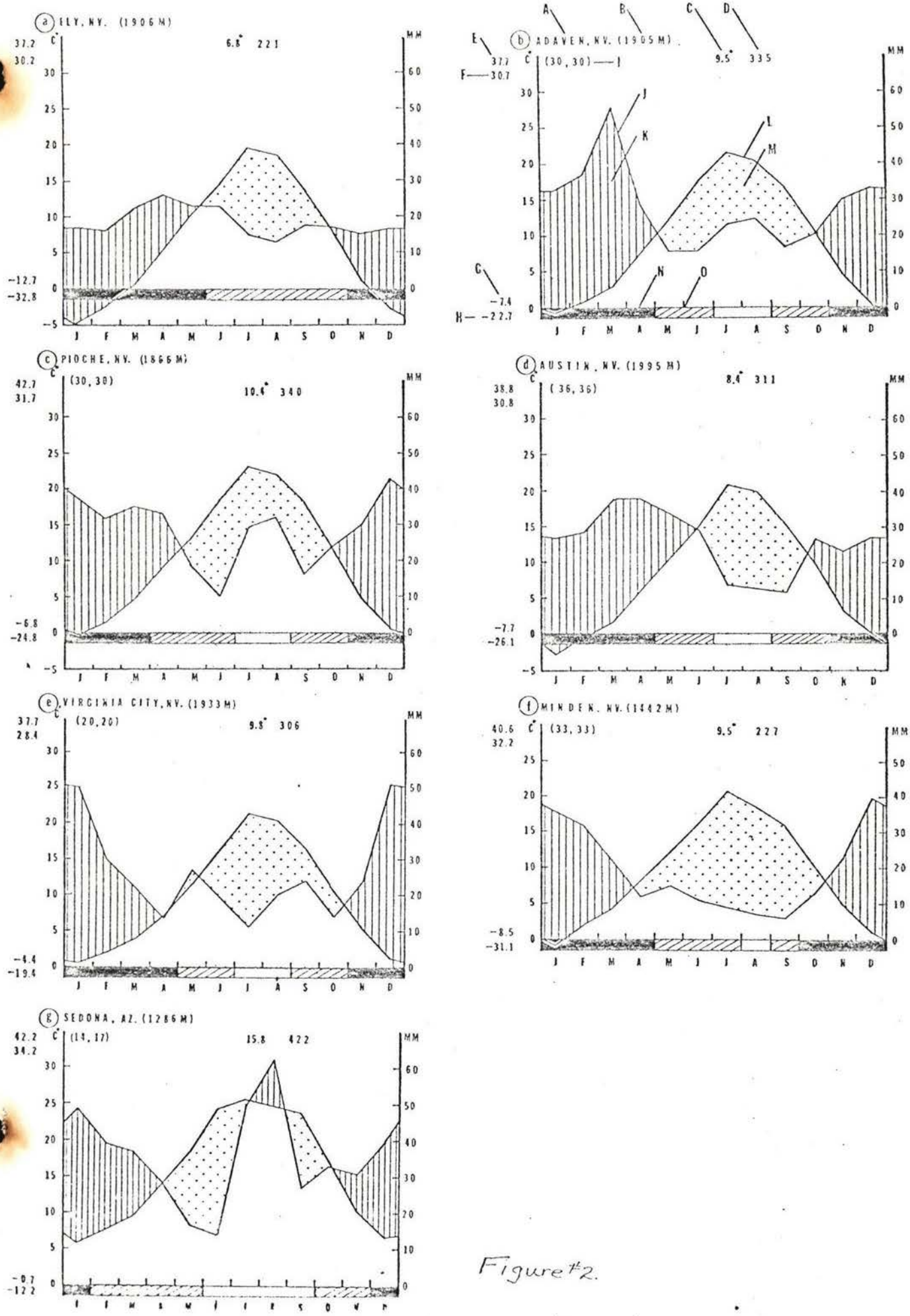
a ELY, NV. (1906 M)
6.8° 221
37.2
30.2
-12.7
-32.8
b ADAVEN, NV. (1905 M)
(30, 30)
9.5° 335
37.7
30.7
-7.4
-22.7
c PIOCHE, NV. (1866 M)
(30, 30)
10.4° 340
42.7
31.7
-6.8
-24.8
d AUSTIN, NV. (1995 M)
(36, 36)
8.4° 311
38.8
30.8
-7.7
-26.1
e VIRGINIA CITY, NV. (1933 M)
(20, 20)
9.8° 306
37.7
28.4
-4.4
-19.4
f MINDEN, NV. (1442 M)
(33, 33)
9.5° 227
40.6
32.2
-8.5
-31.1
g SEDONA, AZ. (1286 M)
(14, 17)
15.8 422
42.2
34.2
-0.7
-12.2
J F M A M J J A S O N D
MM
°C

Figure #2.

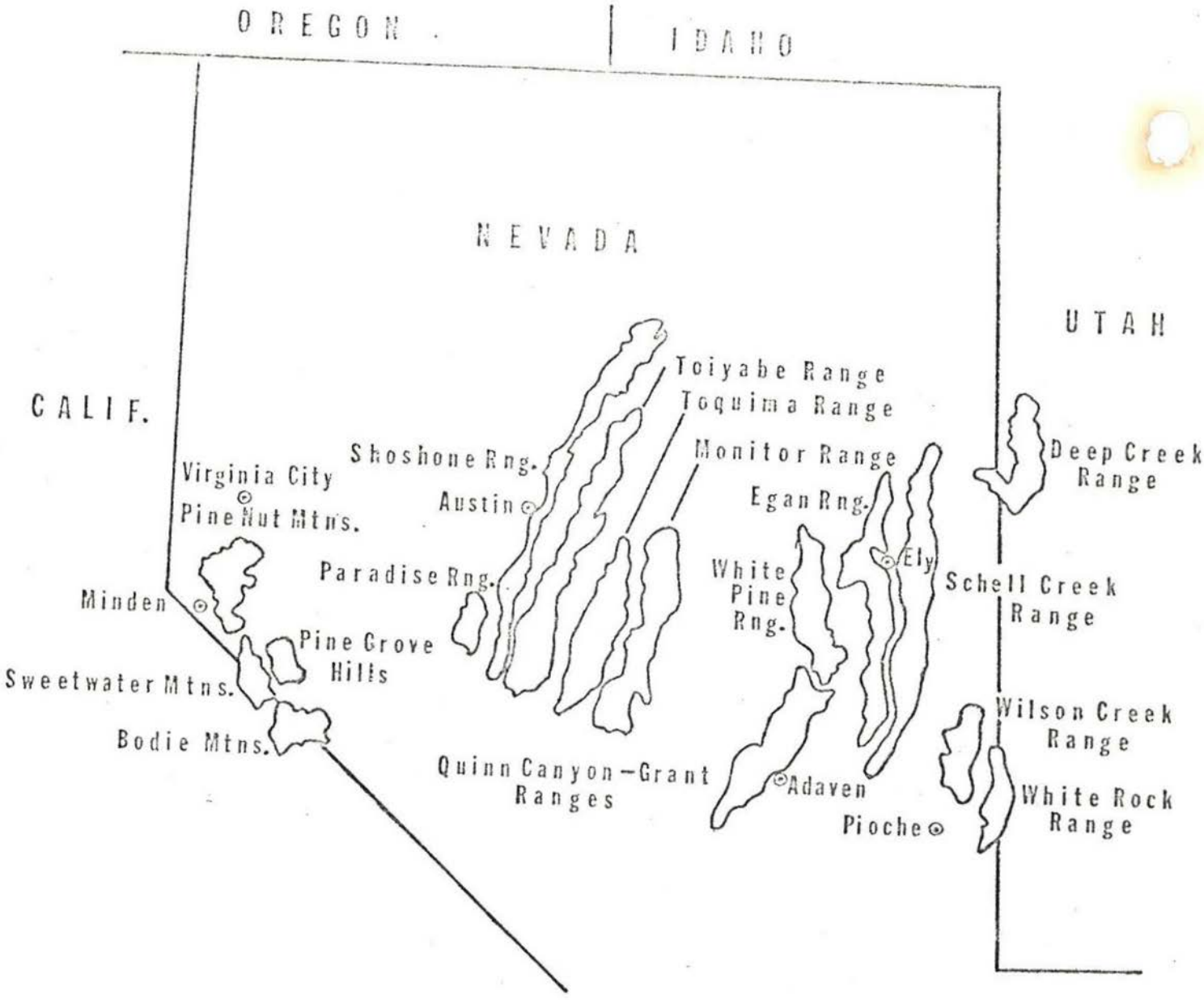
OREGON
IDAHO
NEVADA
UTAH
CALIF.
Toiyabe Range
Toquima Range
Shoshone Rng.
Monitor Range
Deep Creek Range
Virginia City
Pine Nut Mtns.
Austin
Egan Rng.
Paradise Rng.
White Pine Rng.
Ely
Schell Creek Range
Minden
Pine Grove Hills
Sweetwater Mtns.
Wilson Creek Range
Bodie Mtns.
Quinn Canyon–Grant Ranges
Adaven
White Rock Range
Pioche

Fig. 1.

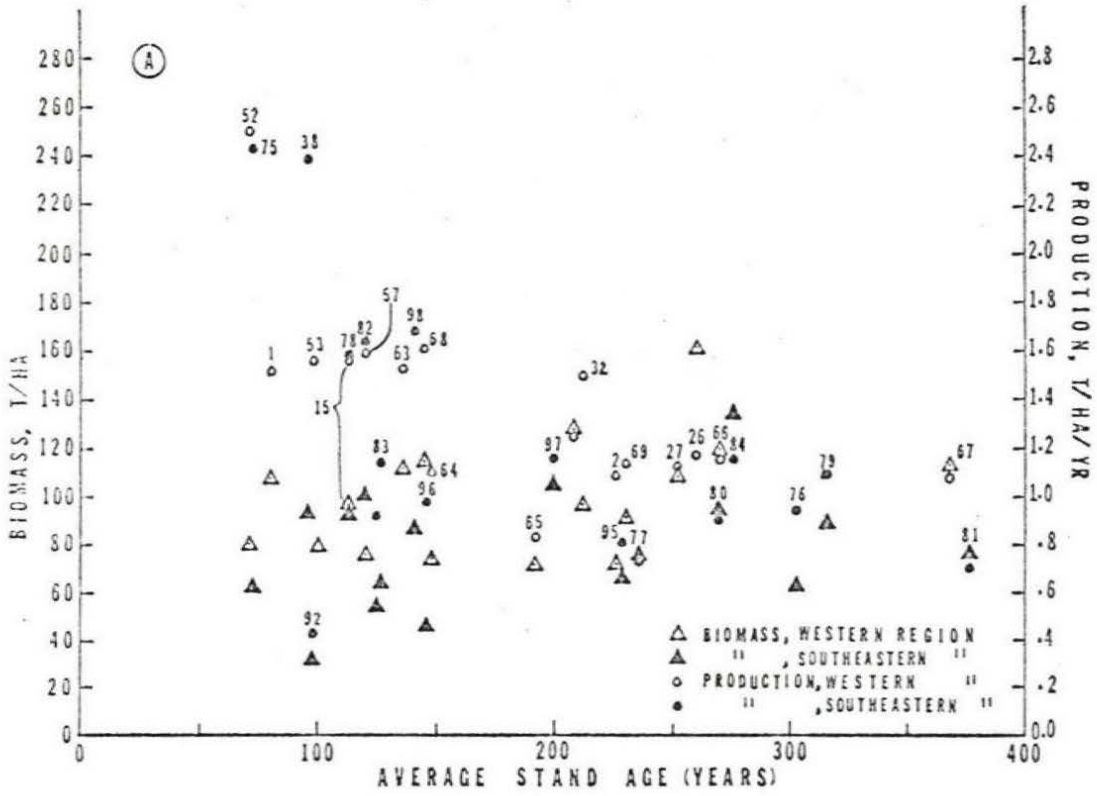
A
BIOMASS, T/HA
PRODUCTION, T/HA/YR
AVERAGE STAND AGE (YEARS)
BIOMASS, WESTERN REGION
" , SOUTHEASTERN "
PRODUCTION, WESTERN "
" , SOUTHEASTERN "

FIG 4a.

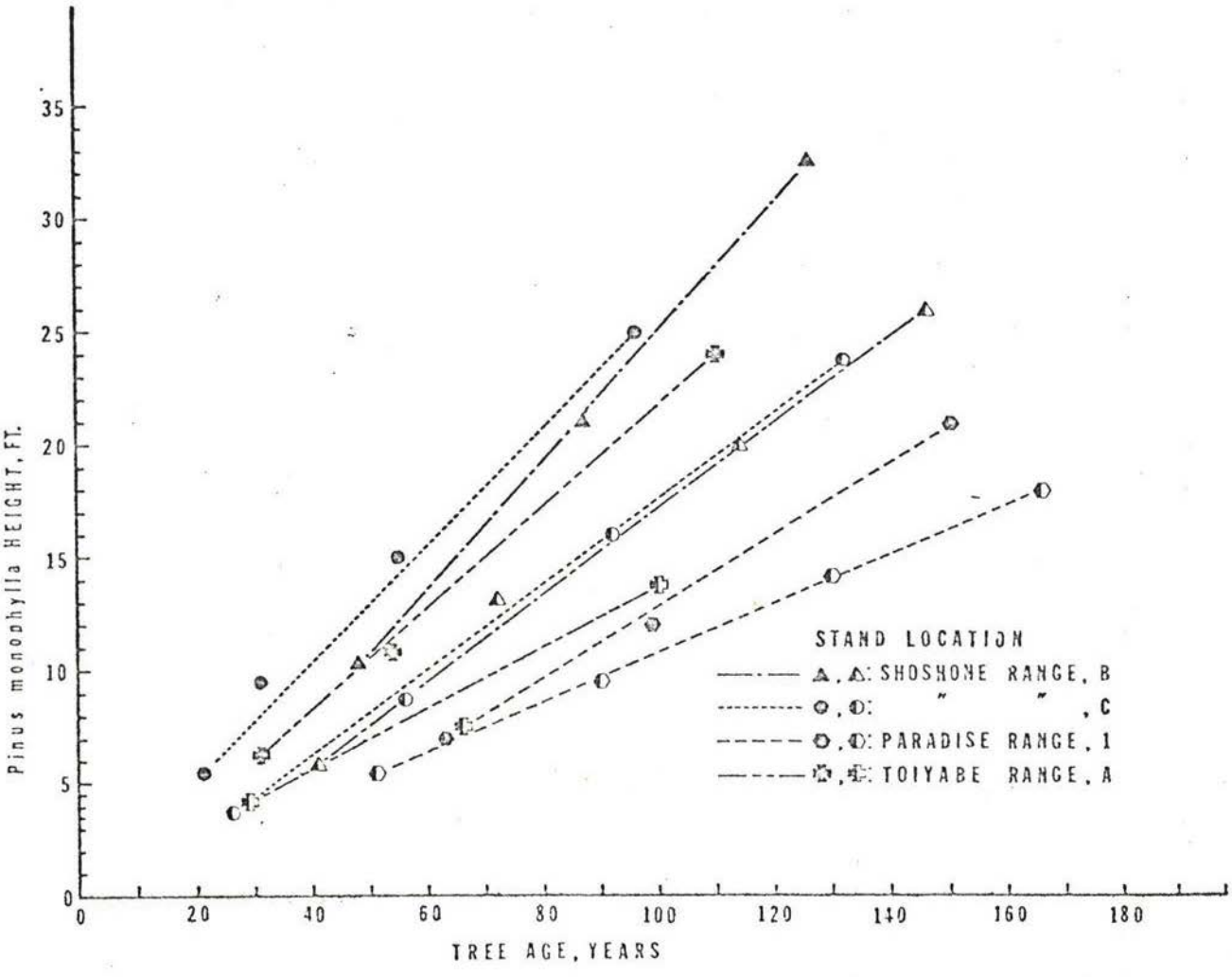
Pinus monophylla HEIGHT, FT.
TREE AGE, YEARS
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160
180
STAND LOCATION
SHOSHONE RANGE, B
" " , C
PARADISE RANGE, 1
TOIYABE RANGE, A

Fig 3.

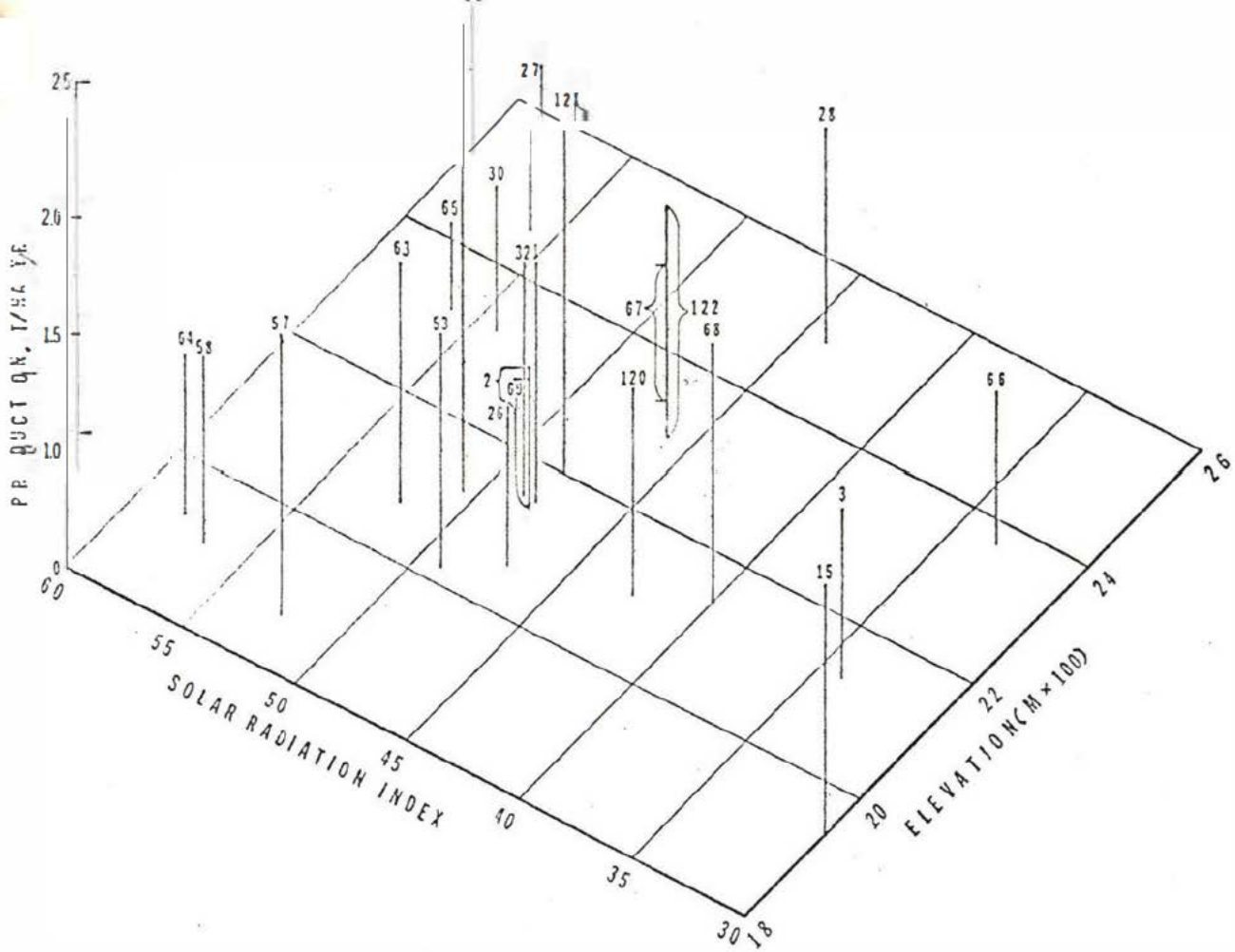
PR QUCT QN. (TON/HA YR
2.5
2.0
1.5
1.0
0
60
55
50
45
40
35
30
SOLAR RADIATION INDEX
18
20
22
24
26
ELEVATION(M×100)
27
121
28
30
65
63
32
64
58
57
53
67
122
68
2
69
26
120
66
3
15

FIG. 5.

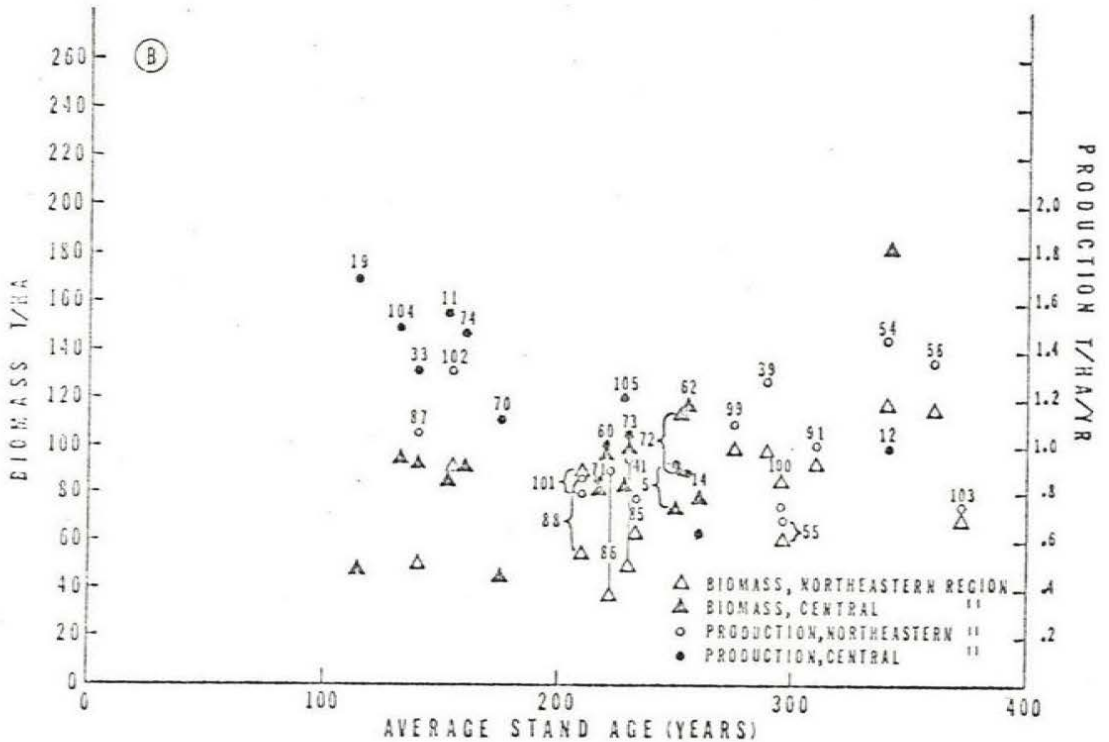

FIG. 4b. (Northeast + Central Regions)